The USGS Geographic Analysis and Monitoring (GAM) Program:

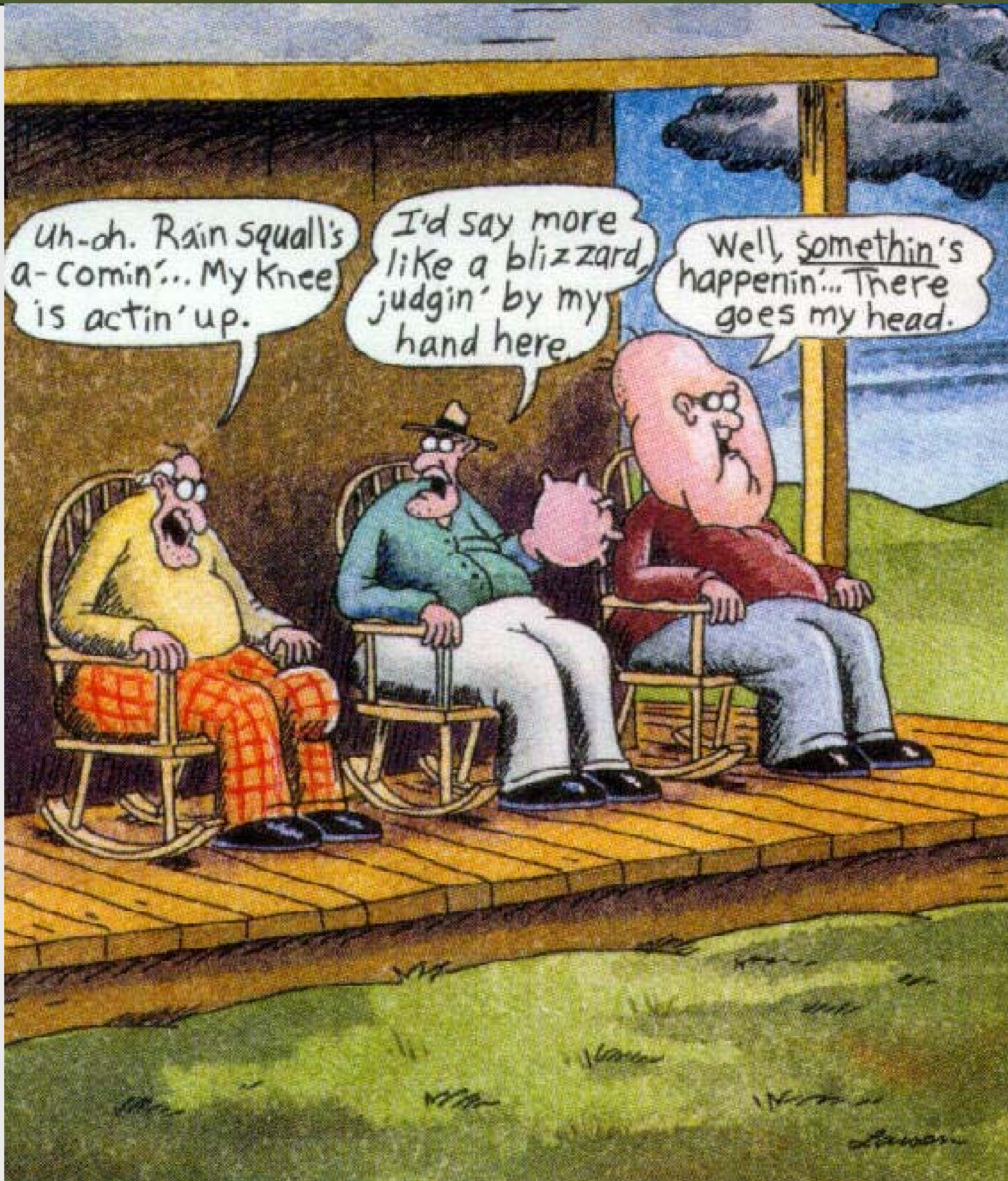
Assessing the rates, causes, and consequences of landscape change

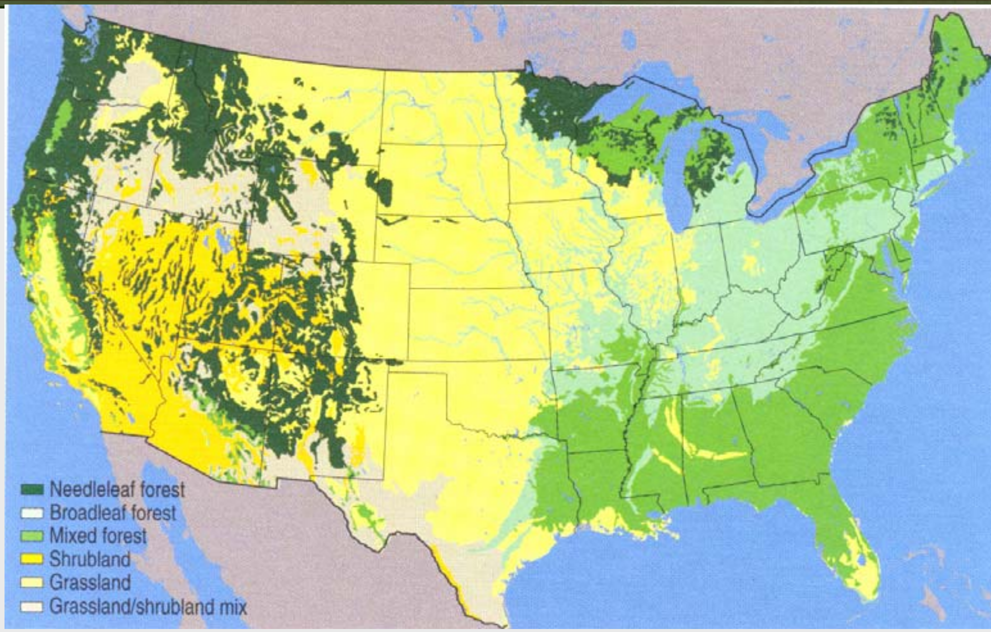
Bradley C. Reed
SAIC
USGS EROS Data Center
Sioux Falls, SD

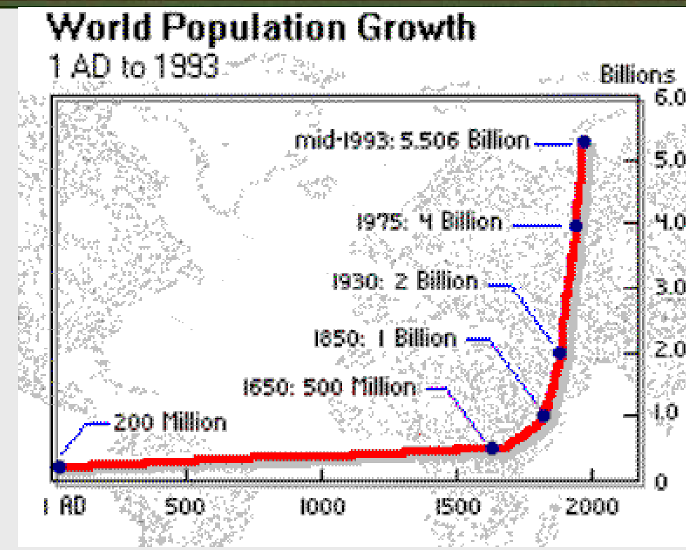
What’s in a name?

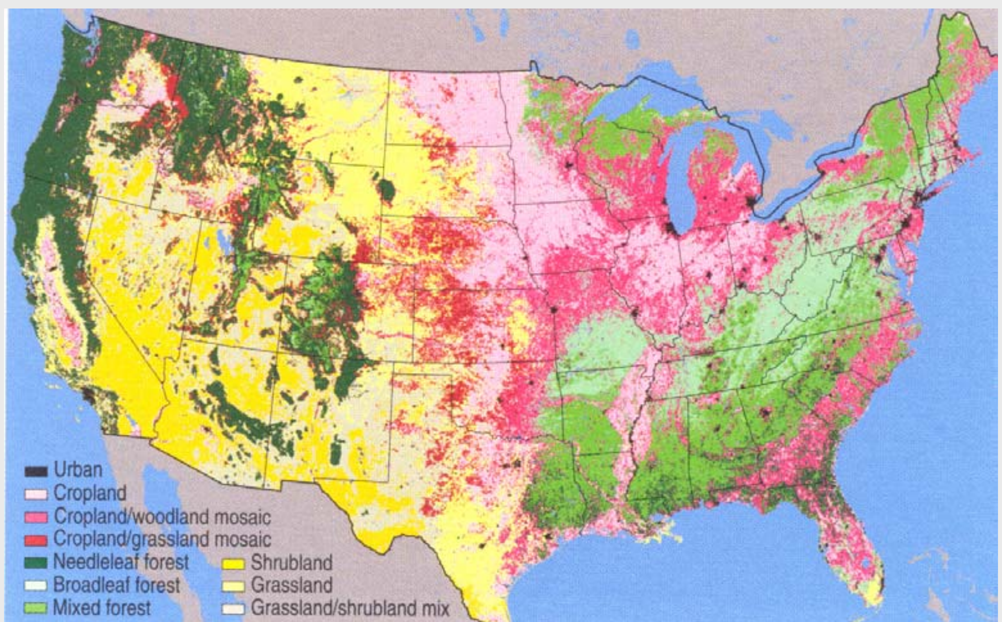
- Terrestrial monitoring
- Environmental monitoring
- Landscape monitoring
- Land surface monitoring
- Land cover monitoring
- Ecosystem monitoring

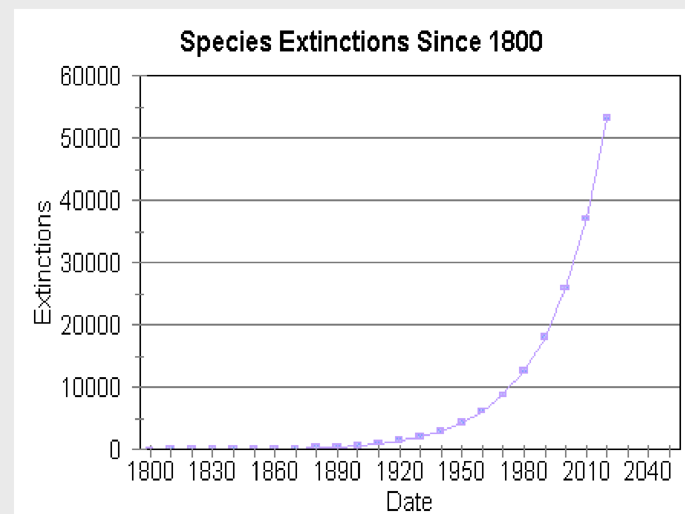
The state-of-the-art in environmental monitoring…

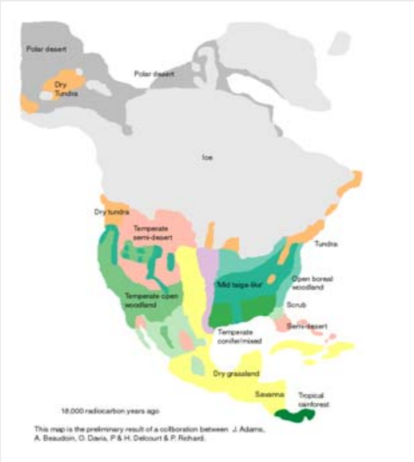


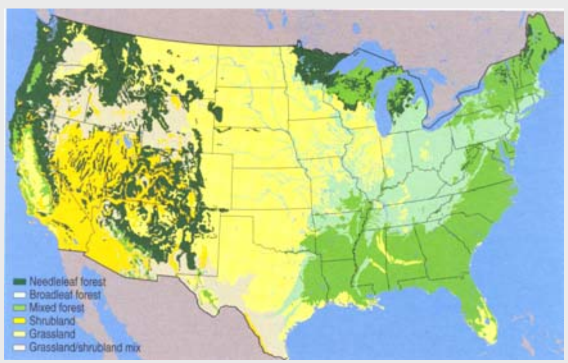

Needleleaf forest
Broadleaf forest
Mixed forest
Shrubland
Grassland
Grassland/shrubland mix


World Population Growth
1 AD to 1993
Billions
6.0
5.0
4.0
3.0
2.0
1.0
0
mid-1993: 5.506 Billion
1975: 4 Billion
1930: 2 Billion
1850: 1 Billion
1650: 500 Million
200 Million
1 AD
500
1000
1500
2000

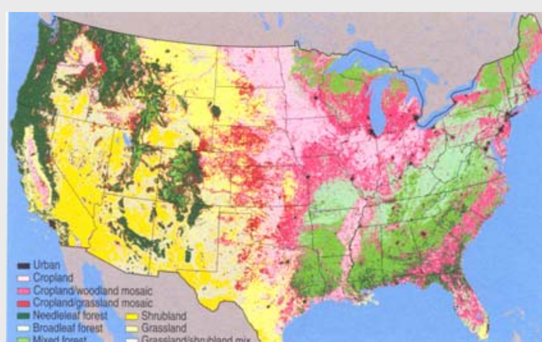

Urban
Cropland
Cropland/woodland mosaic
Cropland/grassland mosaic
Needleleaf forest
Broadleaf forest
Mixed forest
Shrubland
Grassland
Grassland/shrubland mix


Species Extinctions Since 1800
Extinctions
60000
50000
40000
30000
20000
10000
0
1800
1830
1860
1890
1920
1950
1980
2010
2040
Date





Ecosystems change with time, as do the goods and services they provide



Ecosystem Services

- Maintain hydrological cycles
- Regulate climate
- Cleanse water and air
- Maintain the gaseous composition of the atmosphere
- Pollinate crops and other important plants
- Generate and maintain soils
- Store and cycle essential nutrients
- Absorb and detoxify pollutants
- Provide beauty, inspiration, and recreation

Ecosystem Goods

- Food
- Construction materials
- Medicinal plants
- Wild genes for domestic plants and animals
- Tourism and recreation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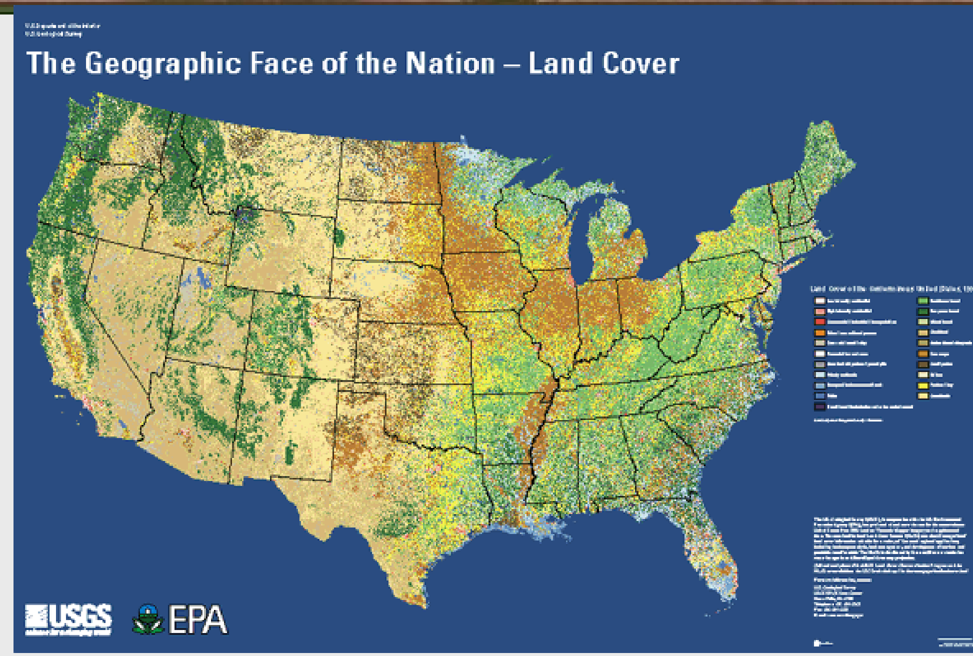
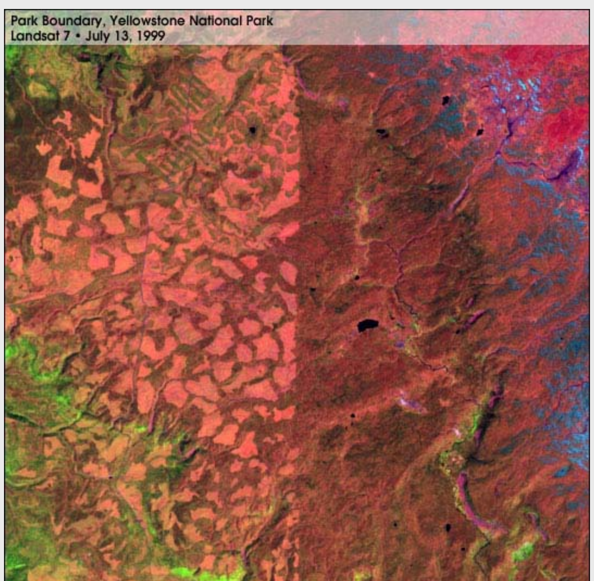
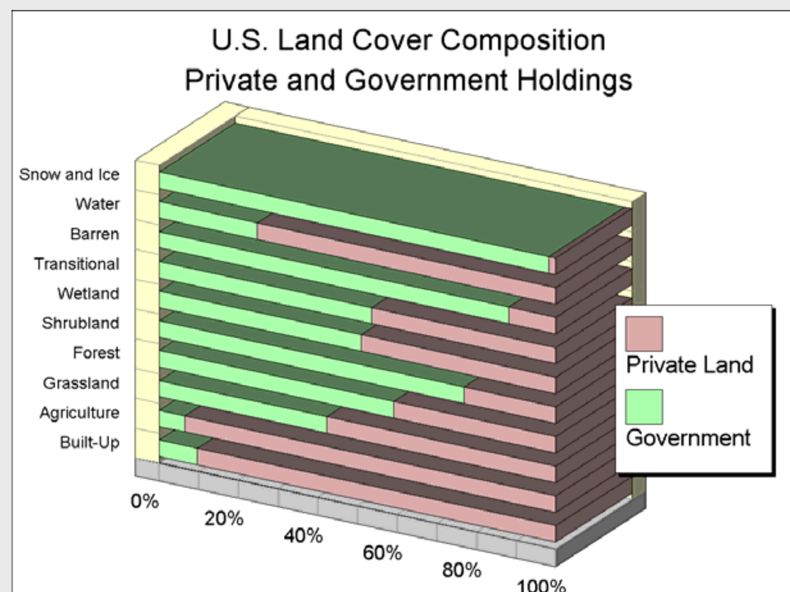

The Geographic Face of the Nation – Land Cover
USGS
EPA


Park Boundary, Yellowstone National Park
Landsat 7 • July 13, 1999


U.S. Land Cover Composition
Private and Government Holdings
Snow and Ice
Water
Barren
Transitional
Wetland
Shrubland
Forest
Grassland
Agriculture
Built-Up
0%
20%
40%
60%
80%
100%
Private Land
Government

Who's Calling for Operational Monitoring?

- Earth Observation Summit
- Climate Change Science Program
- NRC report on Future Roles of the USGS
- NRC Grand Challenges in Environmental Sciences
- *The National Map*
- USGS Geographic Analysis and Monitoring Program – and many other USGS programs
- National Park Service
- U.S. Environmental Protection Agency
- USDA Forest Service…FIA, FHM
- And many others….

Why Now? -- President's FY05 Budget Guidance

- Two of three areas from President Bush's environment and energy budget guidance deal with terrestrial monitoring…

  - Global Climate Change: R&D and monitoring programs "will increase our understanding of climate change science to provide sound climate policy decision-making."

  - Environmental Observations: "A key goal of the Administration's R&D investments is to enhance capabilities to assess and predict key environmental systems."

The Ecosystem Health, Sustainability, and Land Surface Change Future Science Direction Goal:

By 2010, the USGS will have an operational capability to routinely assess the status and trends of our Nation’s ecosystems, and be able to forecast ecosystem status for a period into the future.

The Scientific Questions

Long-term land stewardship can only be established with foresight of the relationship between land surface change and ecosystem health and sustainability. The scientific issues are:

- How do we monitor the health of the Nation's ecosystems?
- How do we assess the cumulative effect on ecosystems of past, present, and anticipated future human and natural impacts?
- How do we asses the future availability of ecosystem benefits?

A Terrestrial Monitoring Vision

To meet the 2010 goal, the USGS must:

- Establish and operate a terrestrial monitoring infrastructure that meets the nation’s needs for timely, accurate, and comprehensive information and knowledge on landscape state and condition – which leads to improved resource management and environmental health.

An infrastructure for understanding the consequences of landscape dynamics…

- **Monitoring the state and condition of the land surface.**
  - **State** is the type and structure of land cover (e.g., forest, grassland), use (e.g., grazing), and management (e.g., improvements, rotation cycles, etc.)
  - **Condition** is the status of the biogeophysical properties and processes of the surface.

Monitoring Components

- Multi-scale remotely sensed observations
- *In situ* measurements
- Process models for interpreting landscape processes and trends (e.g., net ecosystem productivity, landscape fragmentation, etc.)
- Spatial framework for analysis and reporting
- Assessment and reporting

A monitoring system should be sufficiently flexible to shift emphasis from global to national, regional and local scales.

Monitoring Scales

- **Spatial –**
  - Synoptic coverage of US, global monitoring for important variables
  - Multiple spatial scales to address local to global needs
- **Temporal –**
  - Near real-time (e.g., hourly daily, weekly, monthly) for ephemeral and seasonally changing variables
  - Periodic (e.g., annual, decadal) for more static variables

What variables might be monitored nationally or globally?

- Land cover types
- Biophysical attributes
  - Phenology
  - Vegetation structure (e.g., density, leaf area, etc.)
  - Surface permeability
  - Albedo
  - Vegetation condition index
  - Moisture index
- Landscape patterns and properties (e.g., fragmentation)

Research Issues – Methodological Challenges

- **Methods must be developed for:**
  - Extrapolating between small and large scale observations and research activities
  - Establishing interactions between adjacent ecosystems
  - Monitoring ecosystem processes and land surface change

Research Issues – Assessing Status and Thresholds

- We must evaluate and identify:
  - How ongoing natural and human processes affect ecosystem health and sustainability.
  - Thresholds for irreversible change in ecosystem function

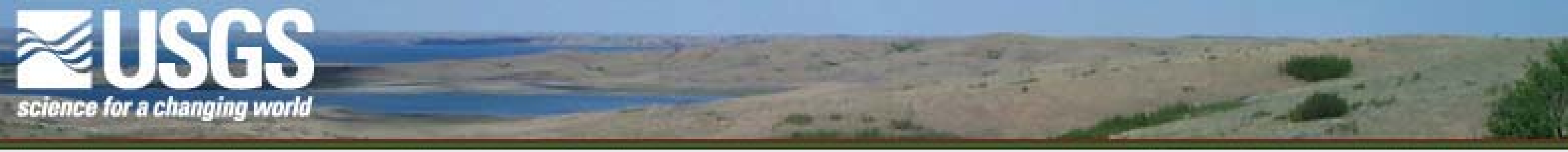
MRLC 2001 (Multi-Resolution Land Characteristics Consortium) Partners

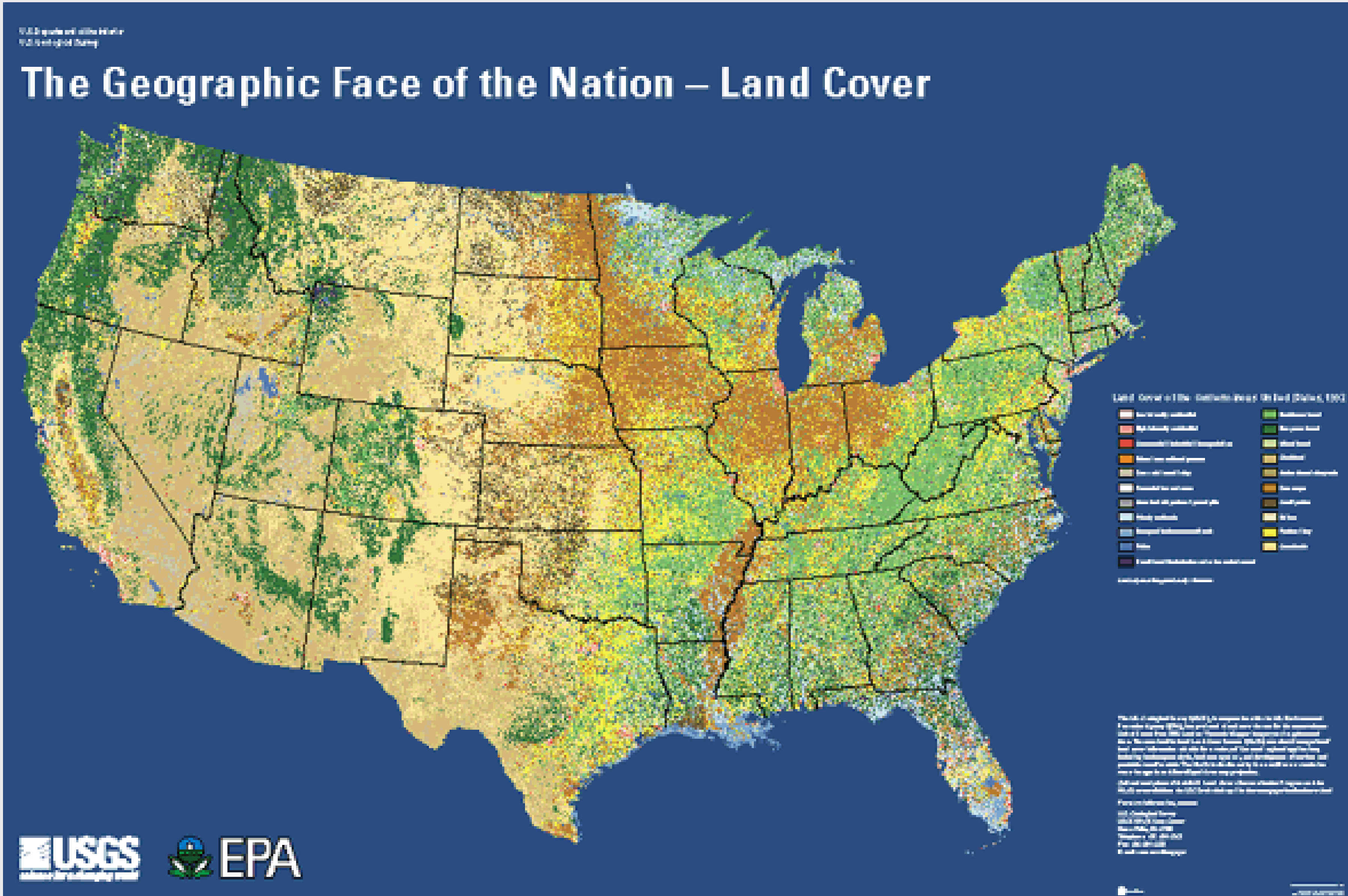
- **Bureau of Land Management**
- **Environmental Protection Agency**
  - **Office of Research and Development**
  - **Environmental Monitoring and Assessment Program**
- **NASA**
- **National Park Service**
- **NOAA**
  - **Costal Change and Analysis Program**
- **NRCS**
  - **National Resource Inventory**
- **US Geological Survey**
  - **National Mapping Division**
  - **Biological Resource Division**
  - **Water Resource Division**
- **US Forest Service**
  - **National Forest Planning**
  - **Forest Inventory and Analysis**

1.) Acquire L-7 Imagery for US
2.) Develop Land cover Database (NLCD)

MRLC Consortium Partners

Fish and Wildlife Service


USGS
science for a changing world


The Geographic Face of the Nation – Land Cover
USGS
EPA

MRLC 2001 National Land Cover Database (NLCD 2001) Guiding Design Principles:

- Make it flexible enough for multiple users
- Provide access to the intermediate database products for local applications
- Develop methods that are objective, consistent and repeatable to allow partnering/contracting…….
- While constraining methods to be as intuitive, simple and efficient as possible
- Maintain compatibility with NLCD 92

NLCD 2001 Database

USGS science for a changing world

Tiled by Mapping Zone

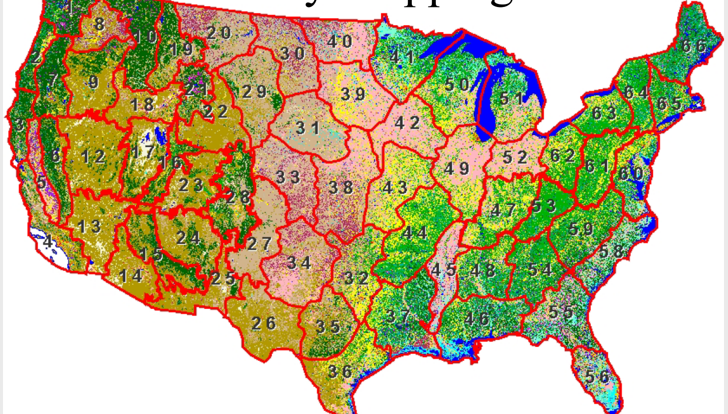
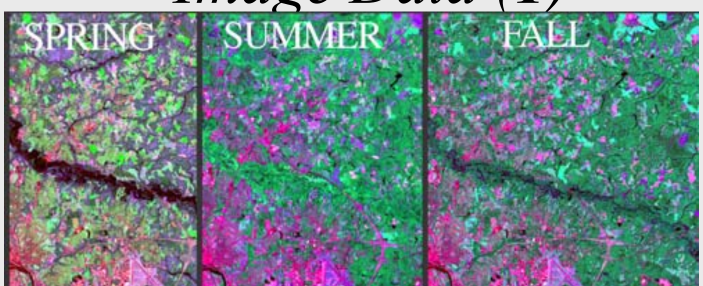
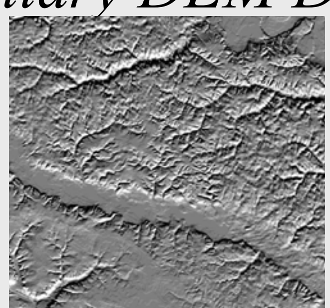


Image Data (1)

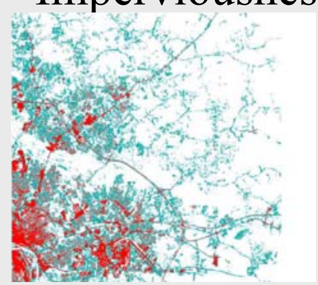


Ancillary DEM Data (2)

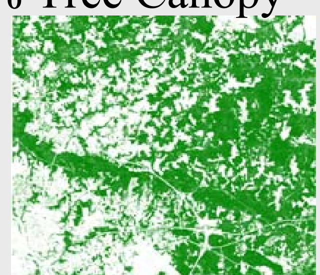


Derivatives (3)

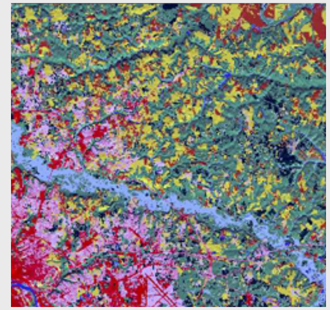
Imperviousness



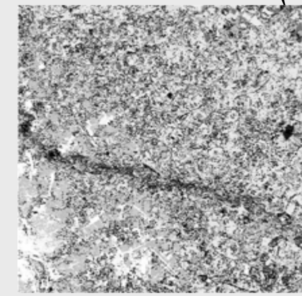
% Tree Canopy

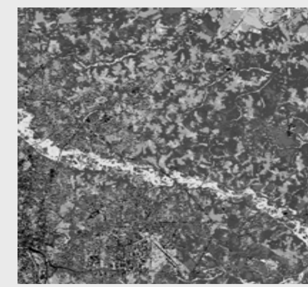


Land cover (4)



Metadata (5)





IF Node_map = 169
& spring TC_green < 73
& summer TC_green > 90
& DEM > 245
& aspect = 9
Then = Deciduous

Cross-Validation Accuracy

[illegible]	REFL_on	REFL_spring	TC_off	TC_on	TC_spring	b9_on	Slope	Soil Quality	Aspect	dem
			x	x		x	x			
			x	x	x	x	x			
x	x									
			x	x						
x	x	x								
			x	x	x					
x	x						x			
			x	x	x		x			
x	x							x		
			x	x	x			x		
x	x					x				
			x	x	x	x				

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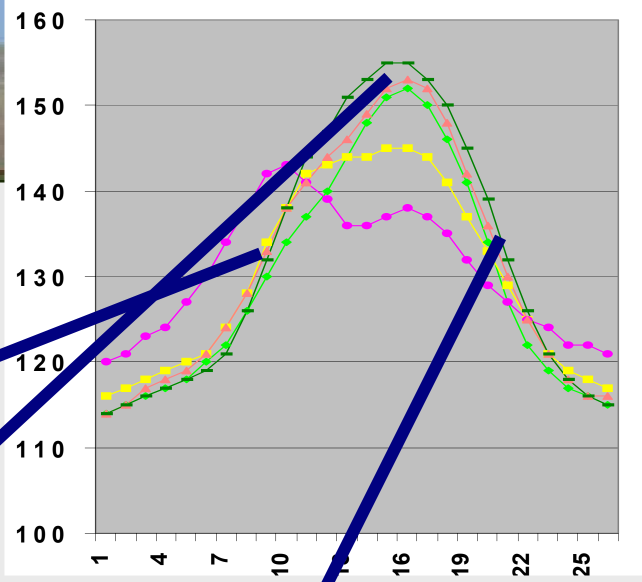
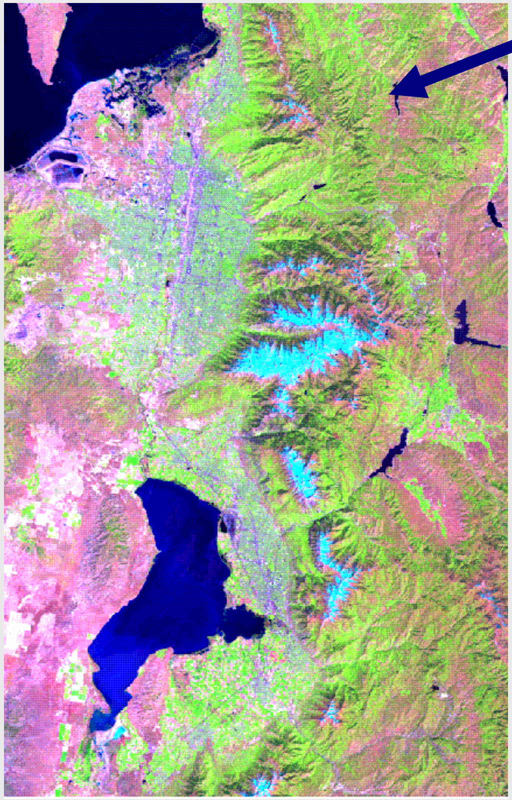
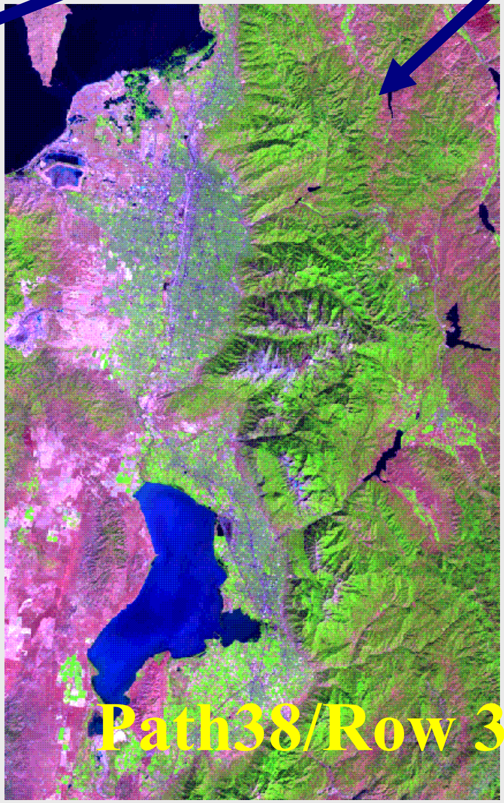
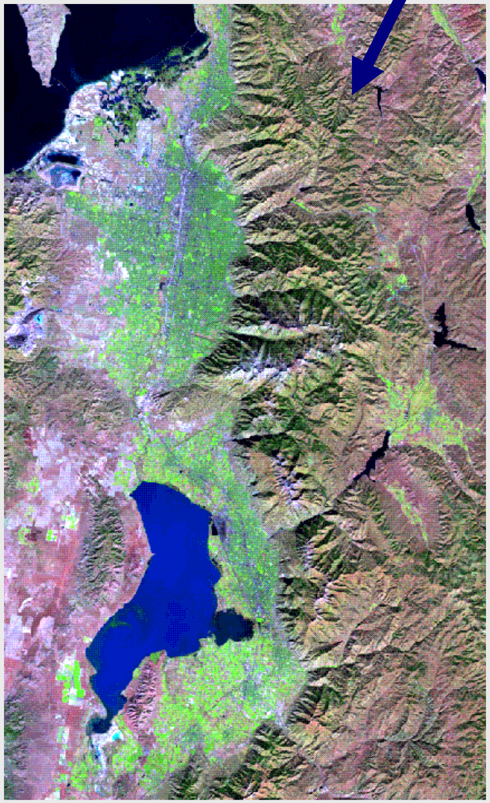
3 dates of imagery per path/row

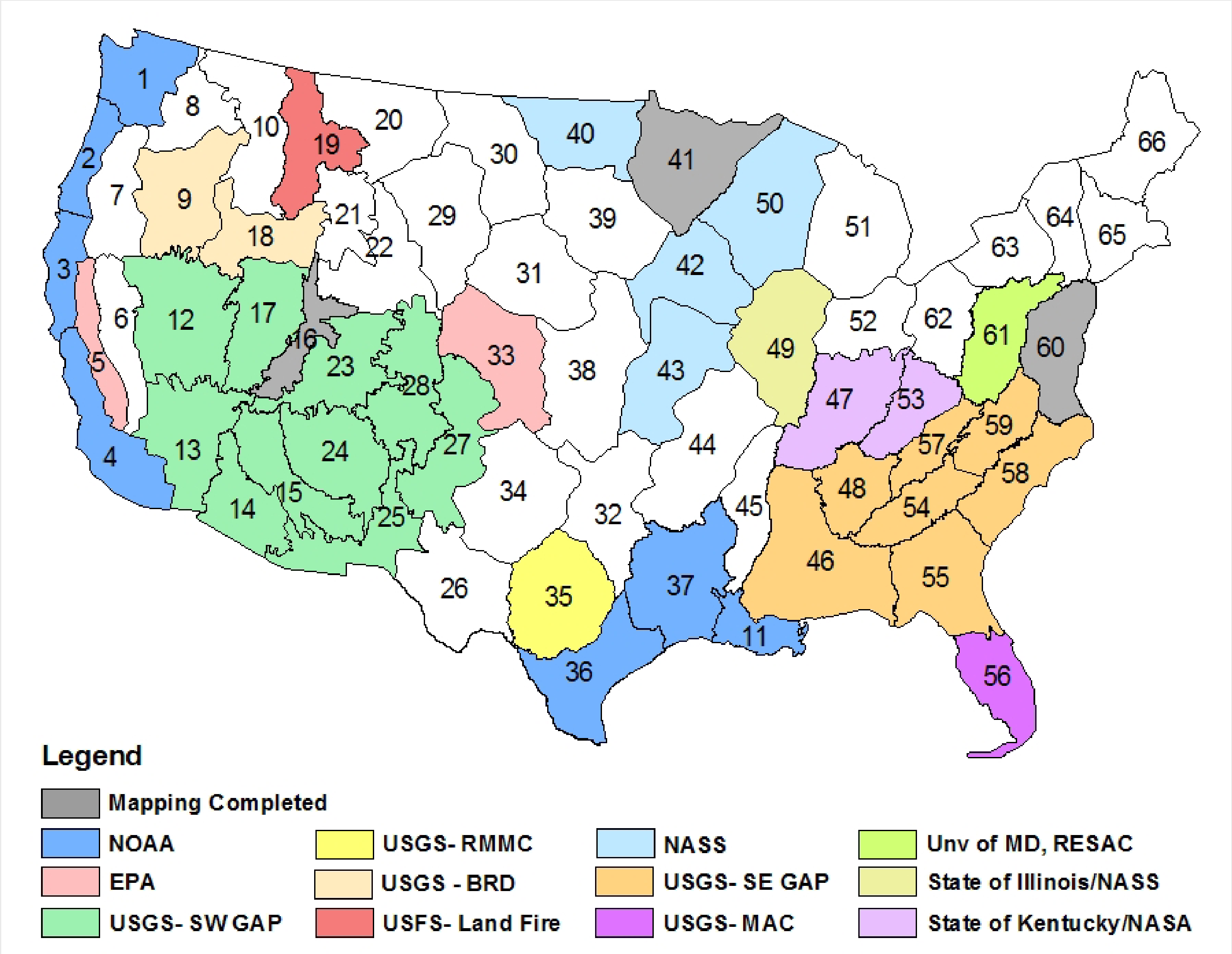




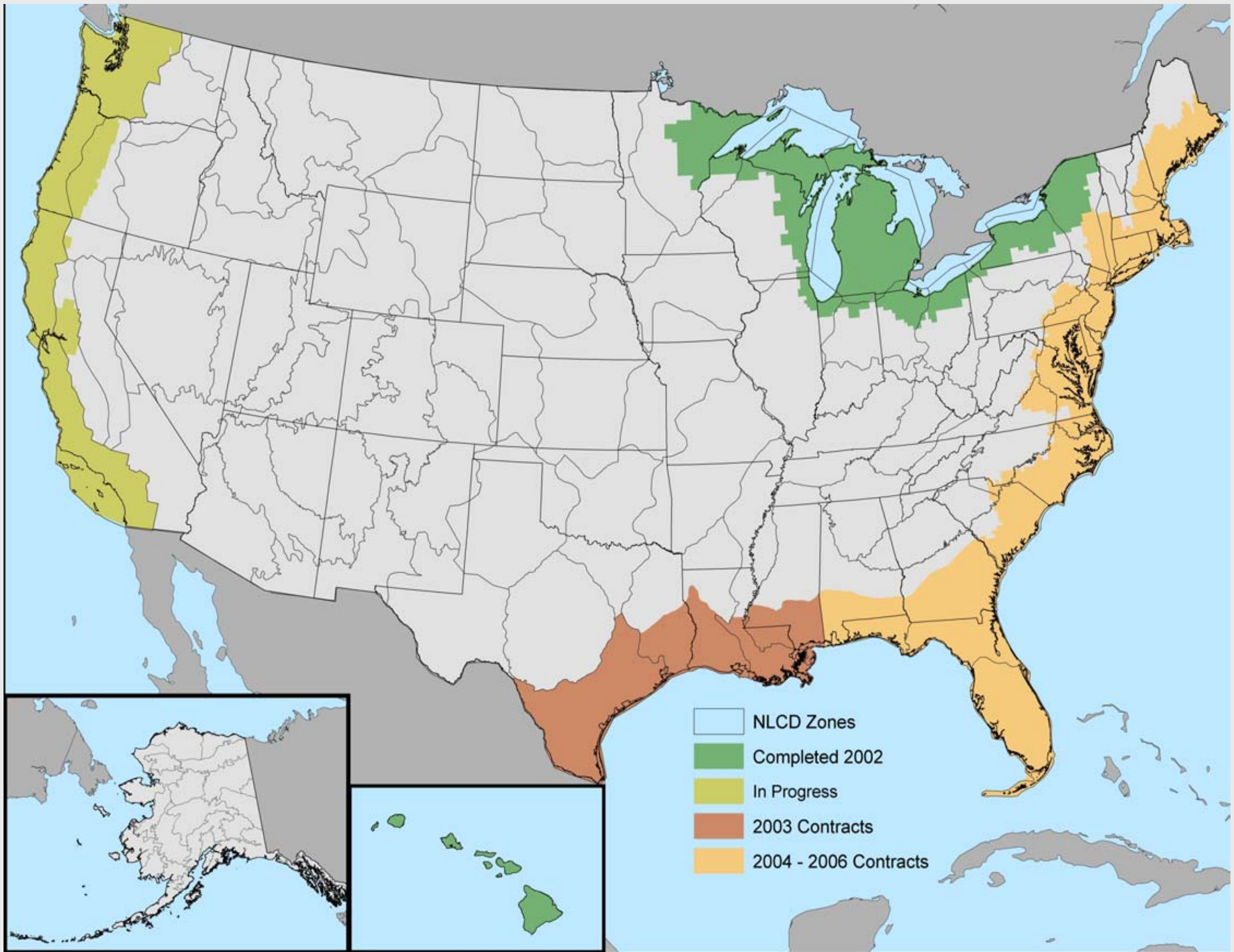




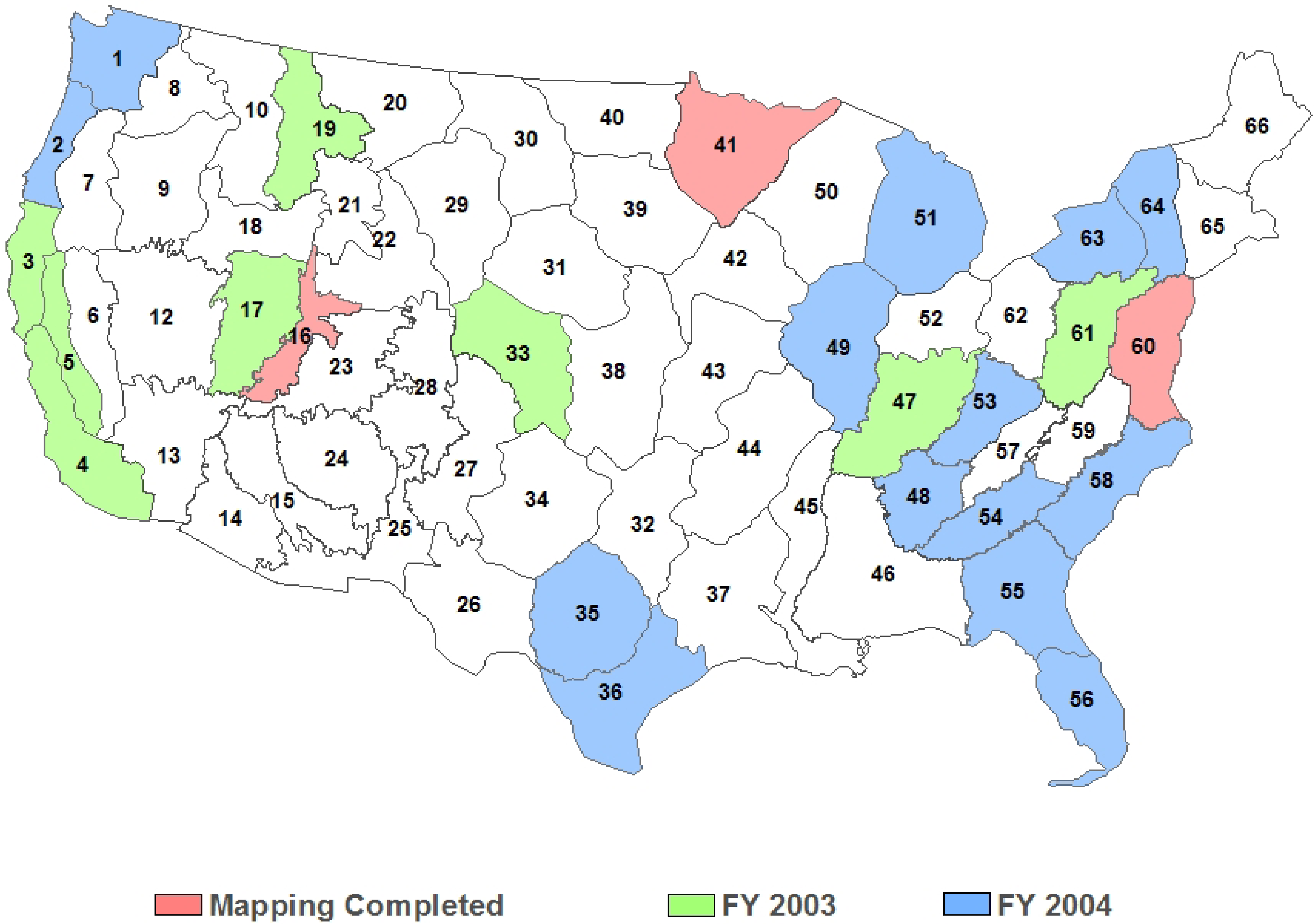
Lead Land Cover Partner, by NLCD 2001 Mapping Zone



NOAA CCAP is responsible for "Coastal" NLCD



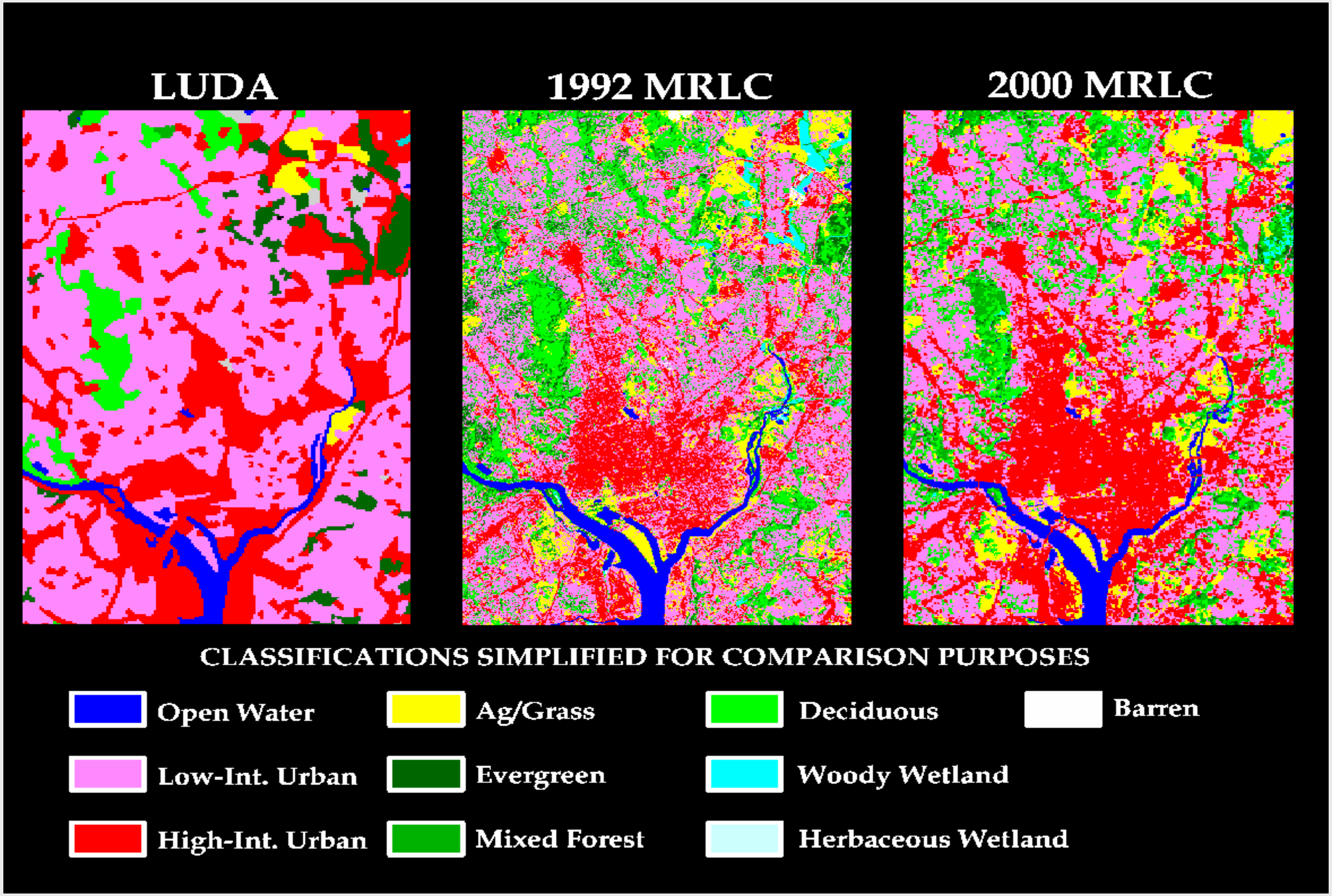
NLCD 2001 Mapping Zone Plan– by Fiscal Year



Estimating Land Cover Change at the Regional and National Levels

Tom Loveland
U.S. Geological Survey
EROS Data Center
Sioux Falls, SD 57198

How do we estimate the rates of land cover change and the types of conversions?



U.S. Land Cover Trends

- Determine the spatial, temporal, and sectoral variability of Conterminous United States land cover change from 1973 to 2000.
- Document the regional driving forces of change.
- Assess the local, regional, and national consequences of Conterminous United States land cover change.

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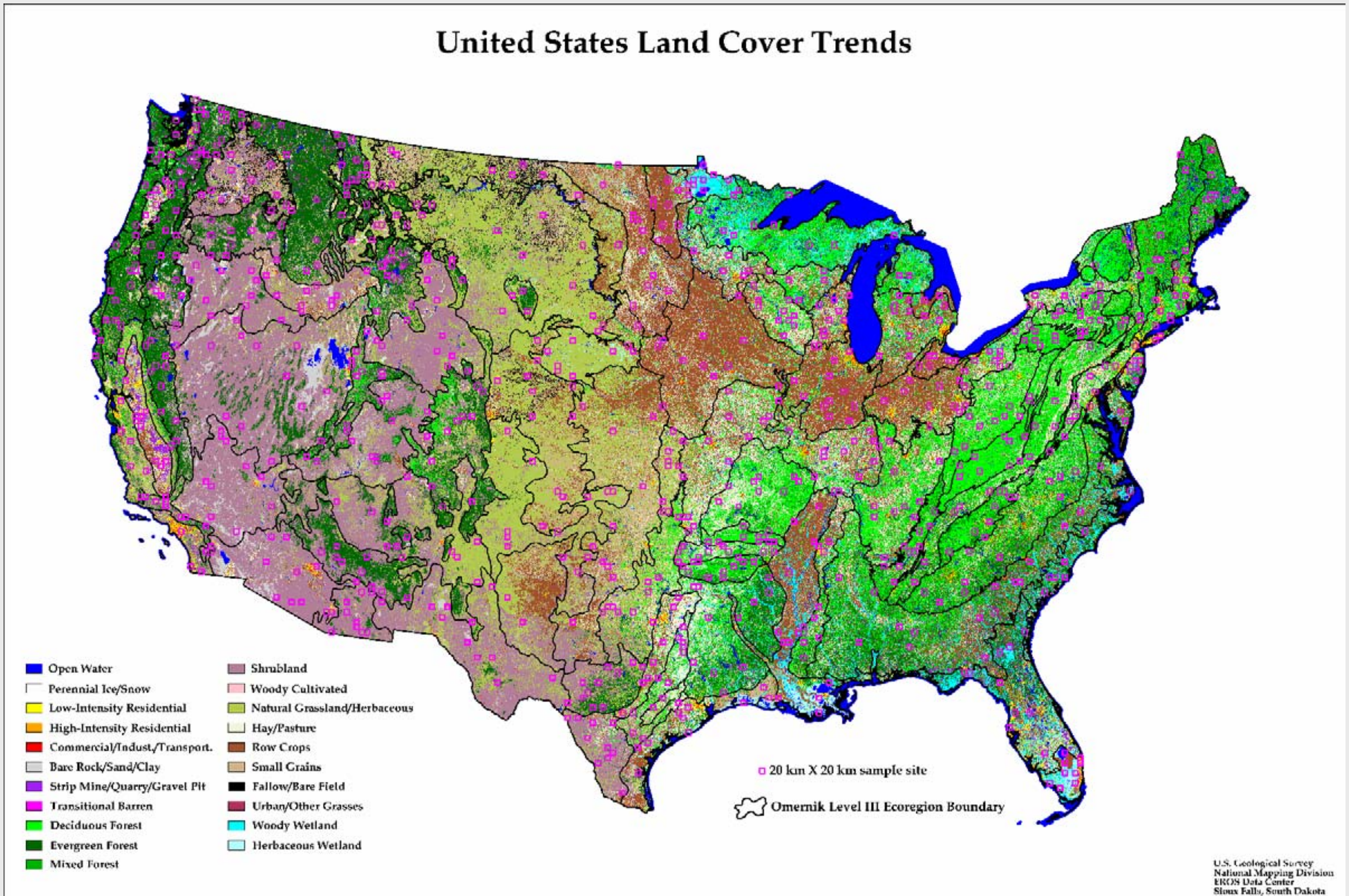
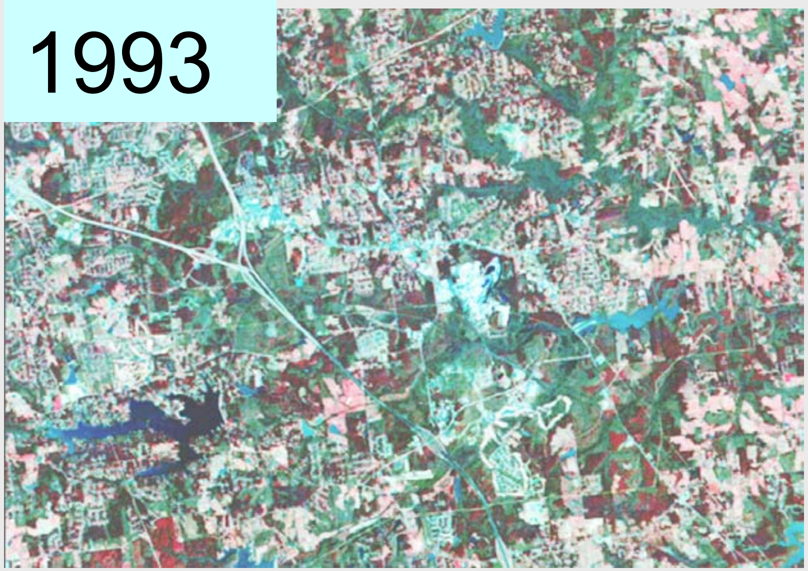
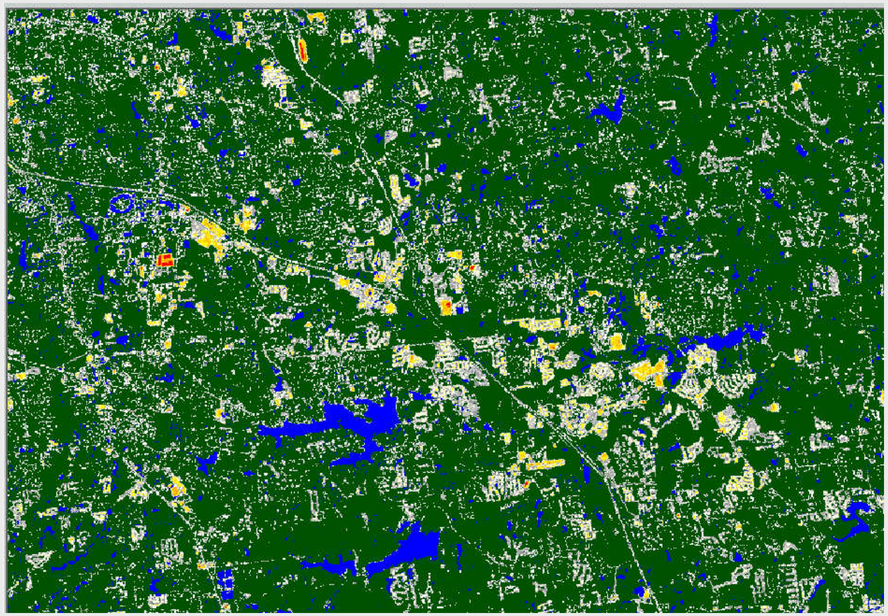
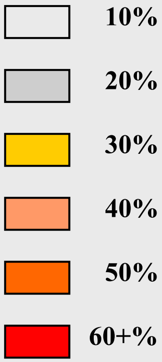
Assessments of change developed for each of 84 ecoregions.



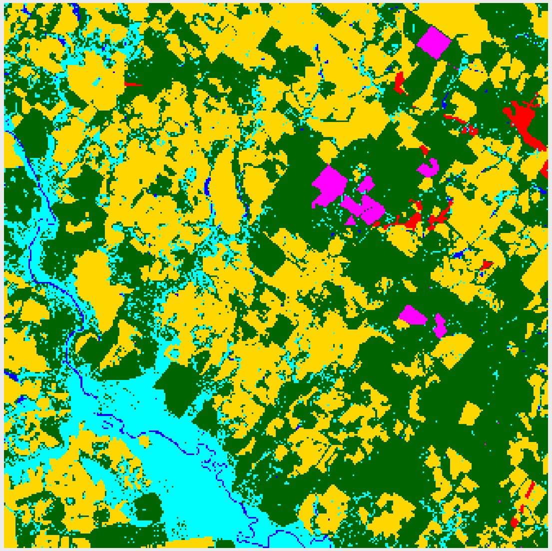




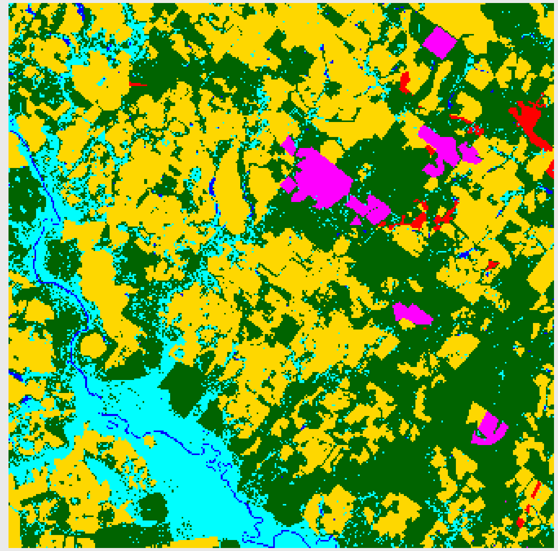
SE Georgia 1991 to 1993 increase in surface permeability



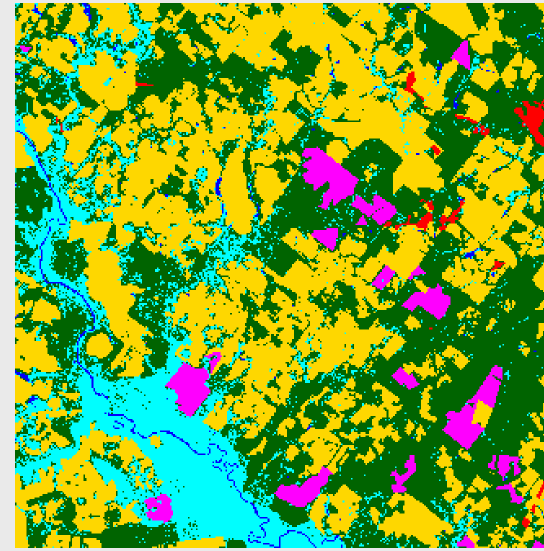
Southeastern Plains



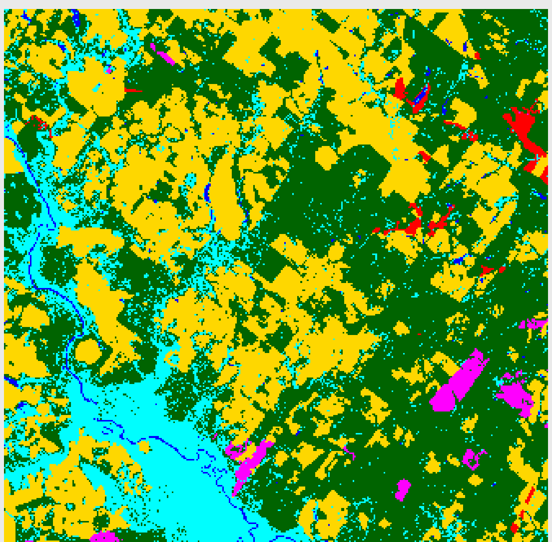
1973



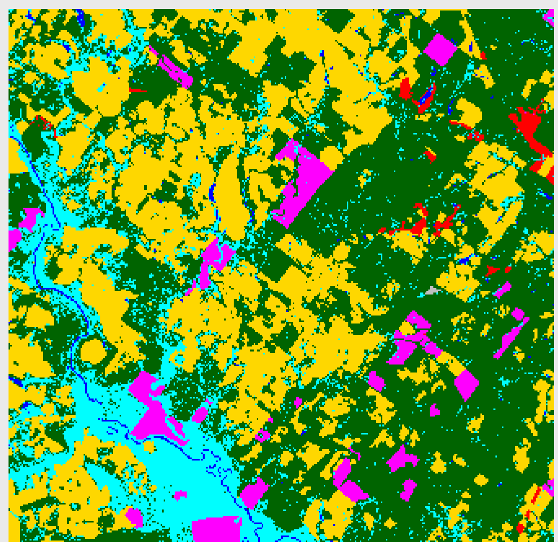
1980



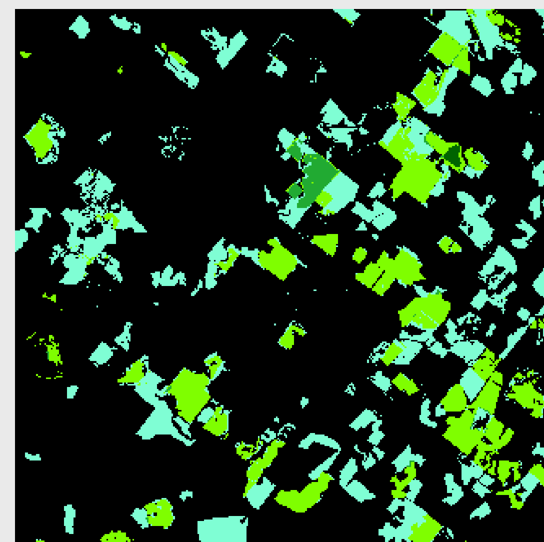
1986



1992



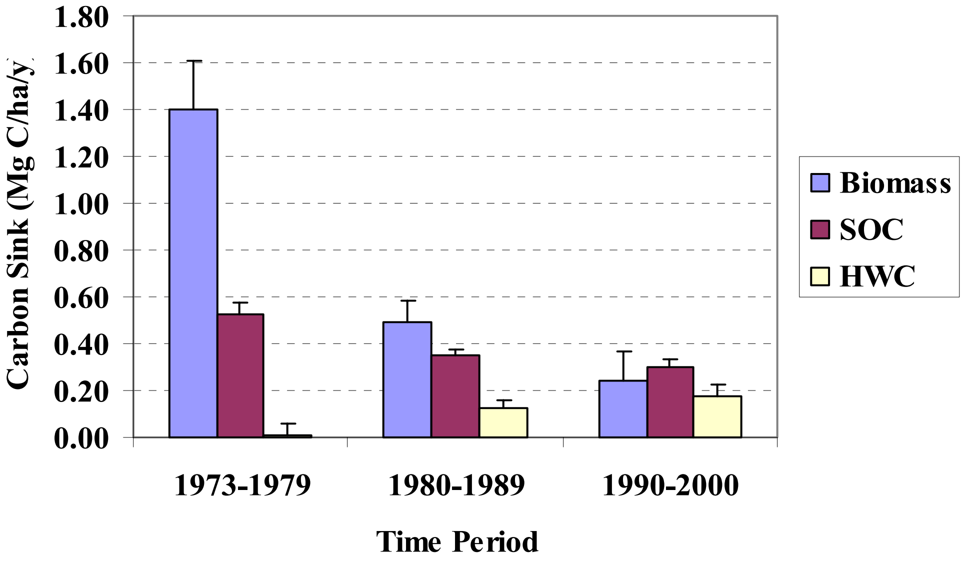
2000

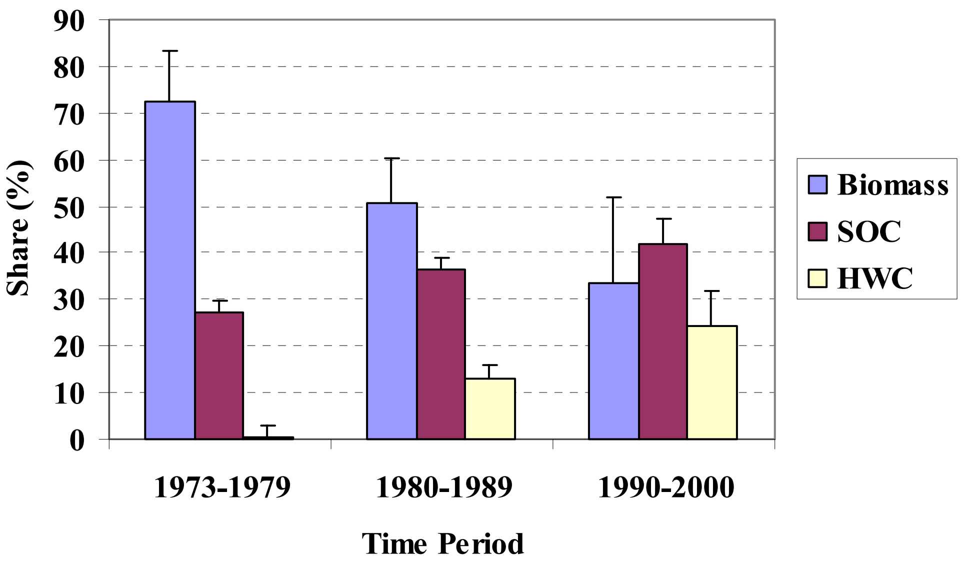


Total Change

Southeastern Plains: Decadal Changes of C Sources and Sinks (1970s to 1990s)

- Total sink: ↓ 65%
- Absolute flux:
  - Biomass ↓
  - soil ↓
  - HWC ↑
- Relative share:
  - Biomass ↓
  - soil ↑
  - HWC ↑





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Remote Sensing and Phenology

Phenology: Study of the timing of biological events

- bird migration
- insect hatching
- plant emergence (crops)
- bud burst
- first leaf

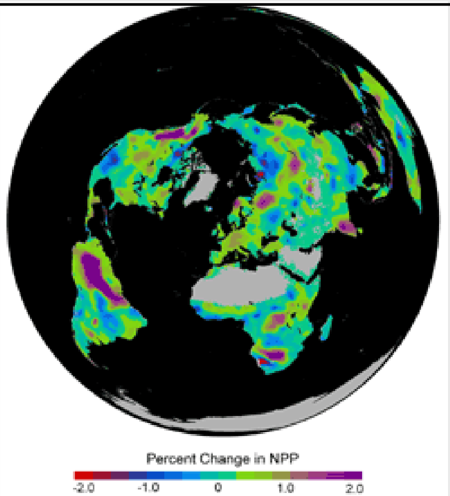
REPORTS

Science, June 6, 2003

Climate-Driven Increases in Global Terrestrial Net Primary Production from 1982 to 1999

Ramakrishna R. Nemani,[1*†] Charles D. Keeling,[2] Hirofumi Hashimoto,[1,3] William M. Jolly,[1] Stephen C. Piper,[2] Compton J. Tucker,[4] Ranga B. Myneni,[5] Steven W. Running[1]

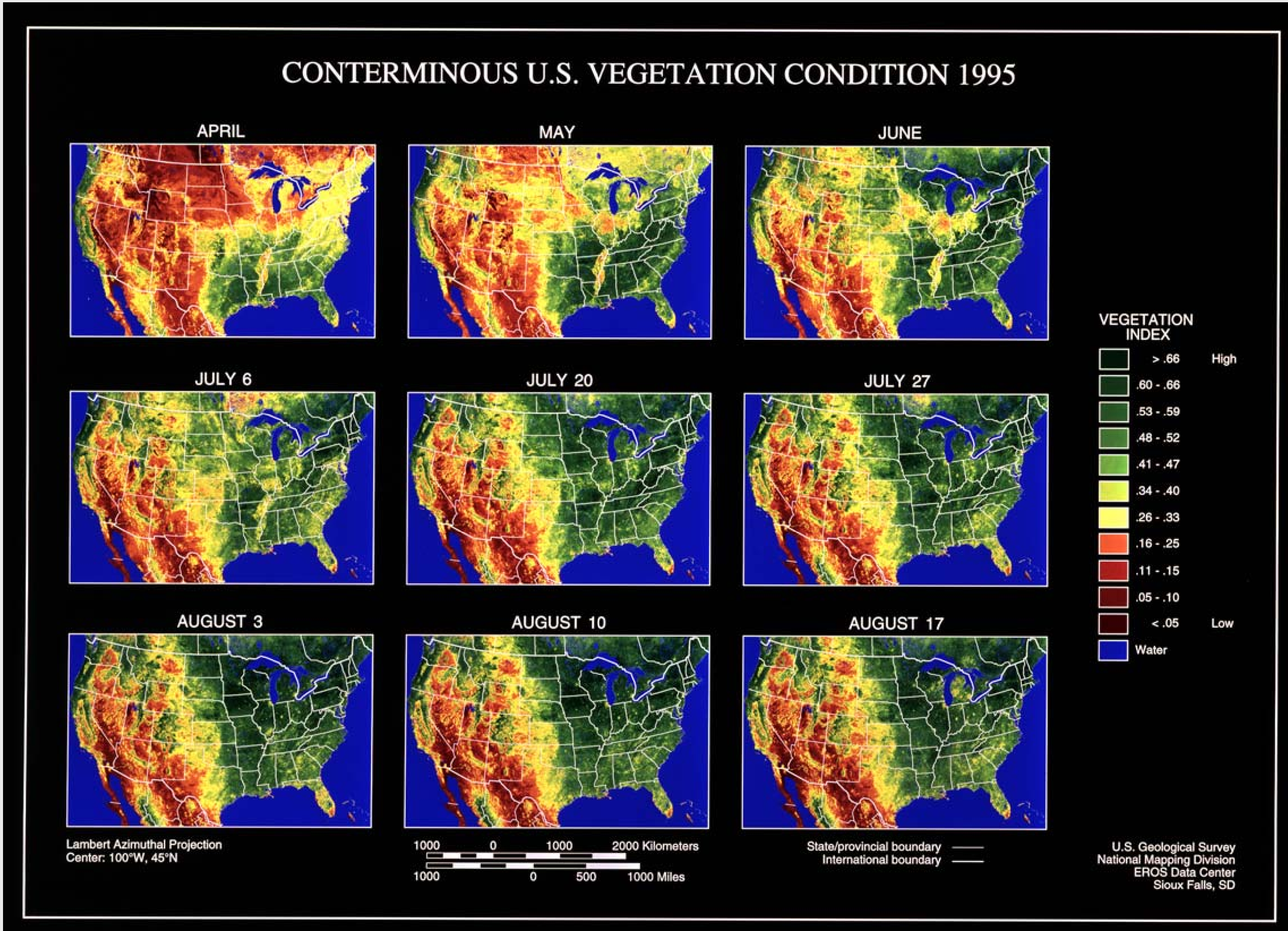
Recent climatic changes have enhanced plant growth in northern mid-latitudes and high latitudes. However, a comprehensive analysis of the impact of global climatic changes on vegetation productivity has not before been expressed in the context of variable limiting factors to plant growth. We present a global investigation of vegetation responses to climatic changes by analyzing 18 years (1982 to 1999) of both climatic data and satellite observations of vegetation activity. Our results indicate that global changes in climate have eased several critical climatic constraints to plant growth, such that net primary production increased 6% (3.4 petagrams of carbon over 18 years) globally. The largest increase was in tropical ecosystems. Amazon rain forests accounted for 42% of the global increase in net primary production, owing mainly to decreased cloud cover and the resulting increase in solar radiation.



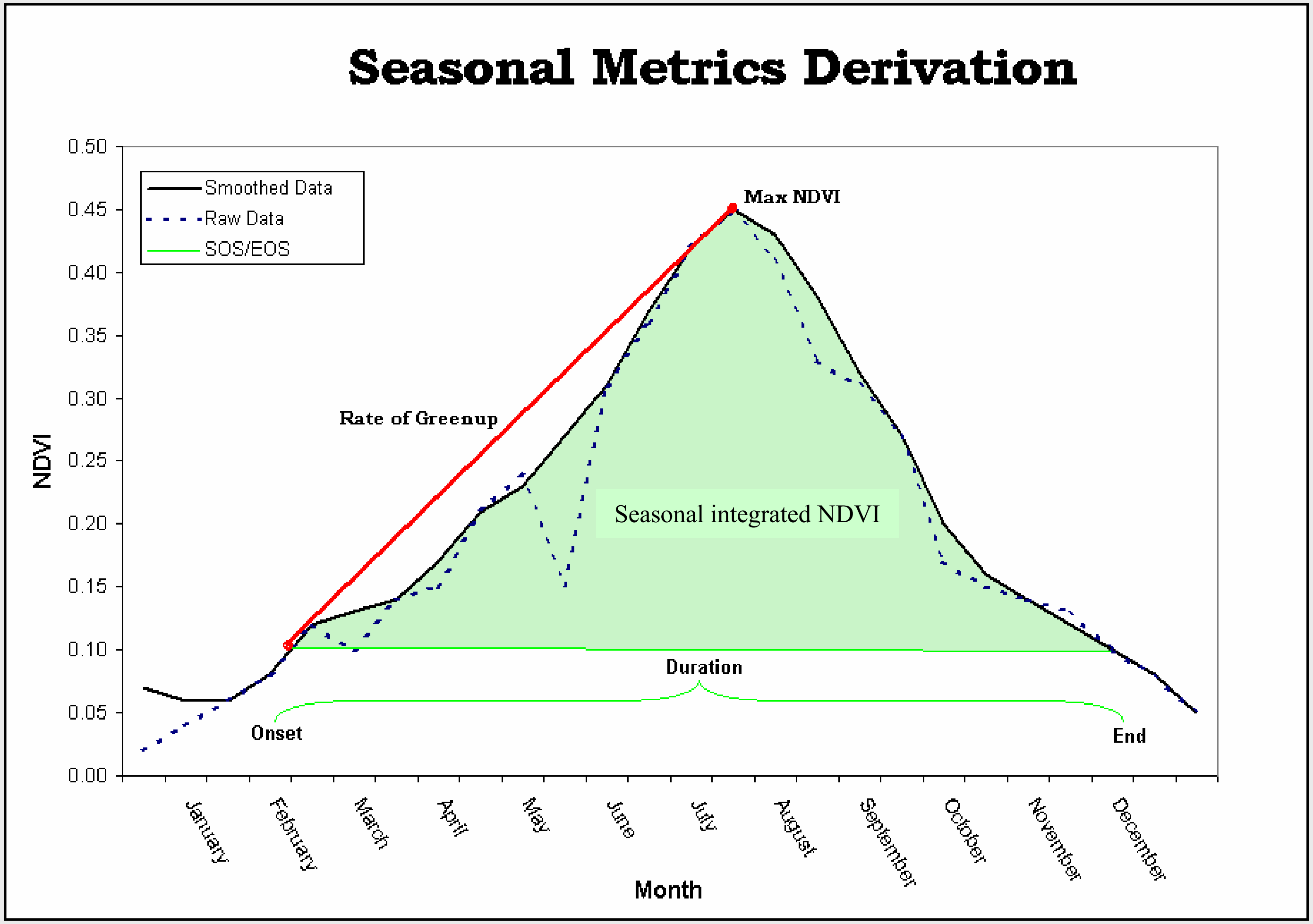
Symptom of global change

Satellite Phenololgy

- Repeatable observations
- Synoptic view
- Ability to derive vegetation (greenness) indices


CONTERMINOUS U.S. VEGETATION CONDITION 1995
APRIL
MAY
JUNE
JULY 6
JULY 20
JULY 27
AUGUST 3
AUGUST 10
AUGUST 17
VEGETATION INDEX
> .66 High
.60 - .66
.53 - .59
.48 - .52
.41 - .47
.34 - .40
.26 - .33
.16 - .25
.11 - .15
.05 - .10
< .05 Low
Water
Lambert Azimuthal Projection
Center: 100°W, 45°N
1000 0 1000 2000 Kilometers
1000 0 500 1000 Miles
State/provincial boundary
International boundary
U.S. Geological Survey
National Mapping Division
EROS Data Center
Sioux Falls, SD

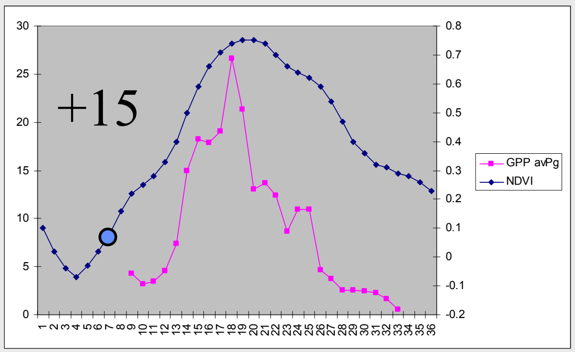
Additional metrics can be derived from the annual VI cycle



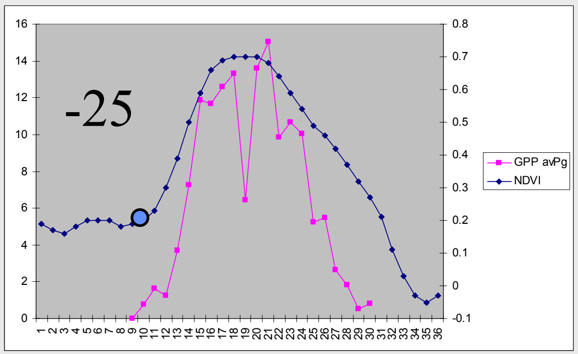
Satellite SOS vs. GPP estimates

(USDA-Agriflux towers)

Mandan, ND



1999



2000

Days offset

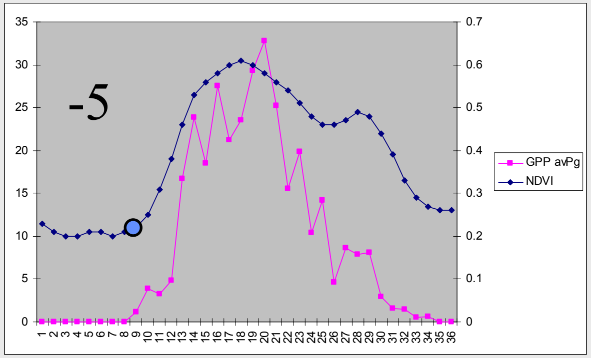
$n = 13$

$\bar{x} = 2.23$

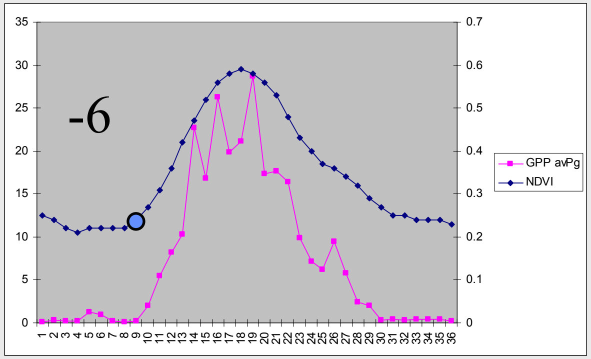
std = 15.21

● = Start of Season

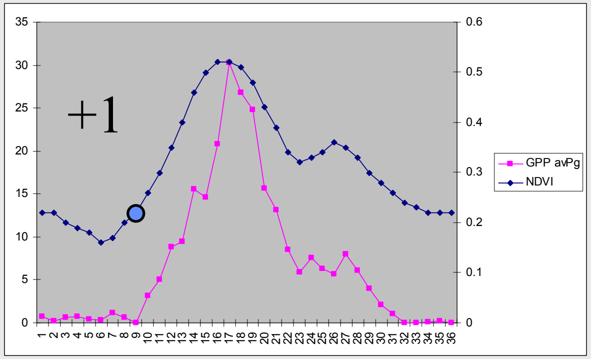
Woodward, OK



1999



2000



2001

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1989


1990


1991


1992


1993


1994


1995


1996

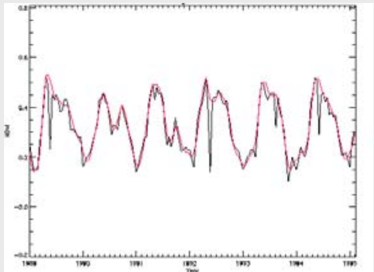

1997


1998


1999

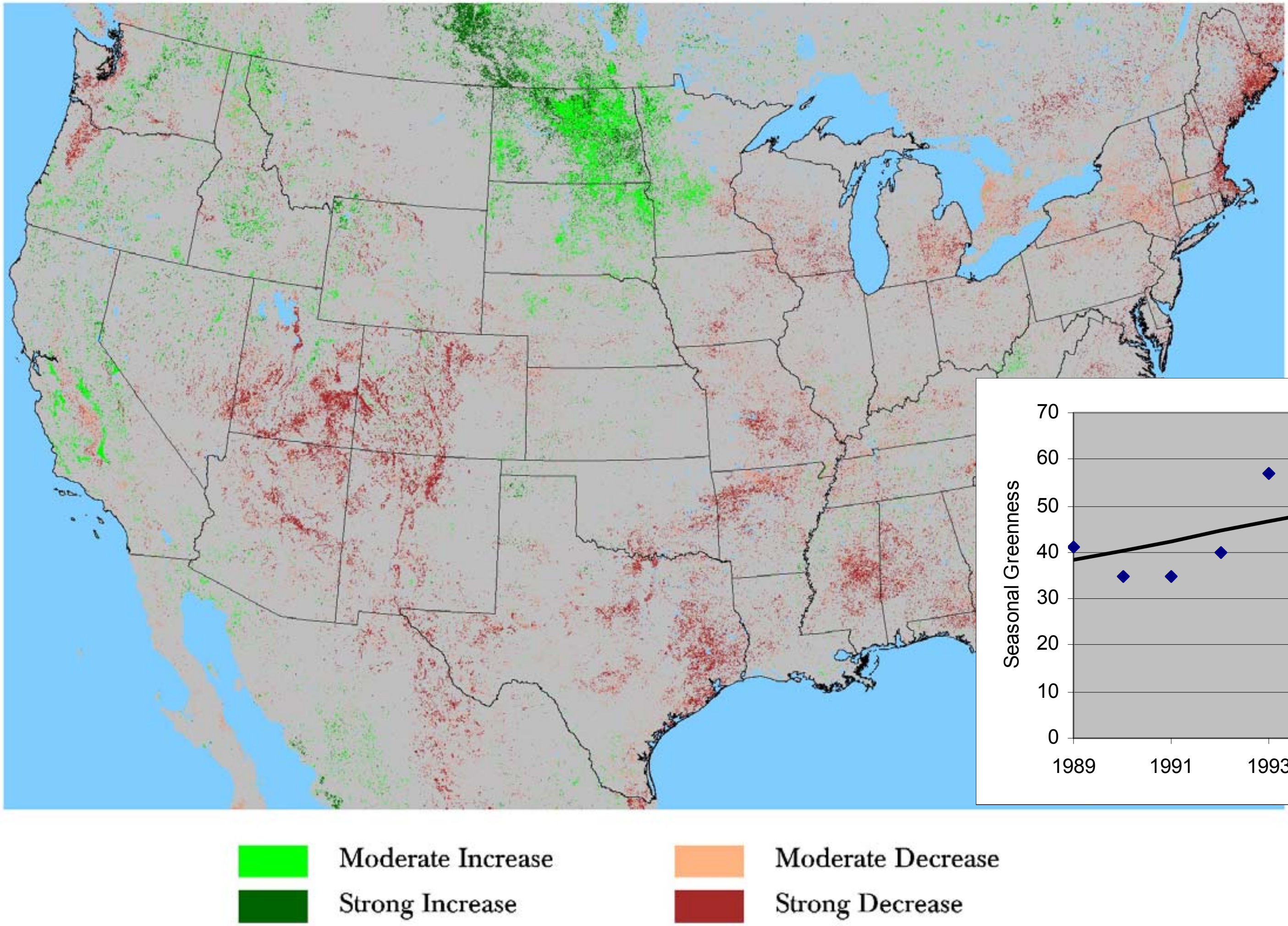

2000

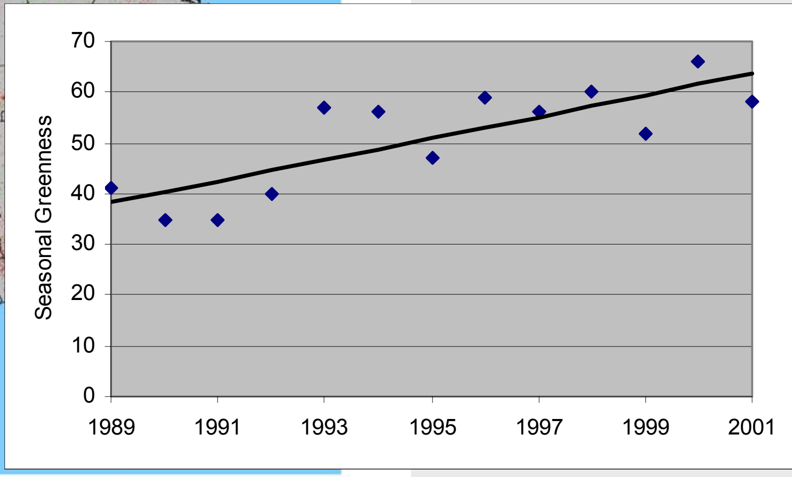

2001



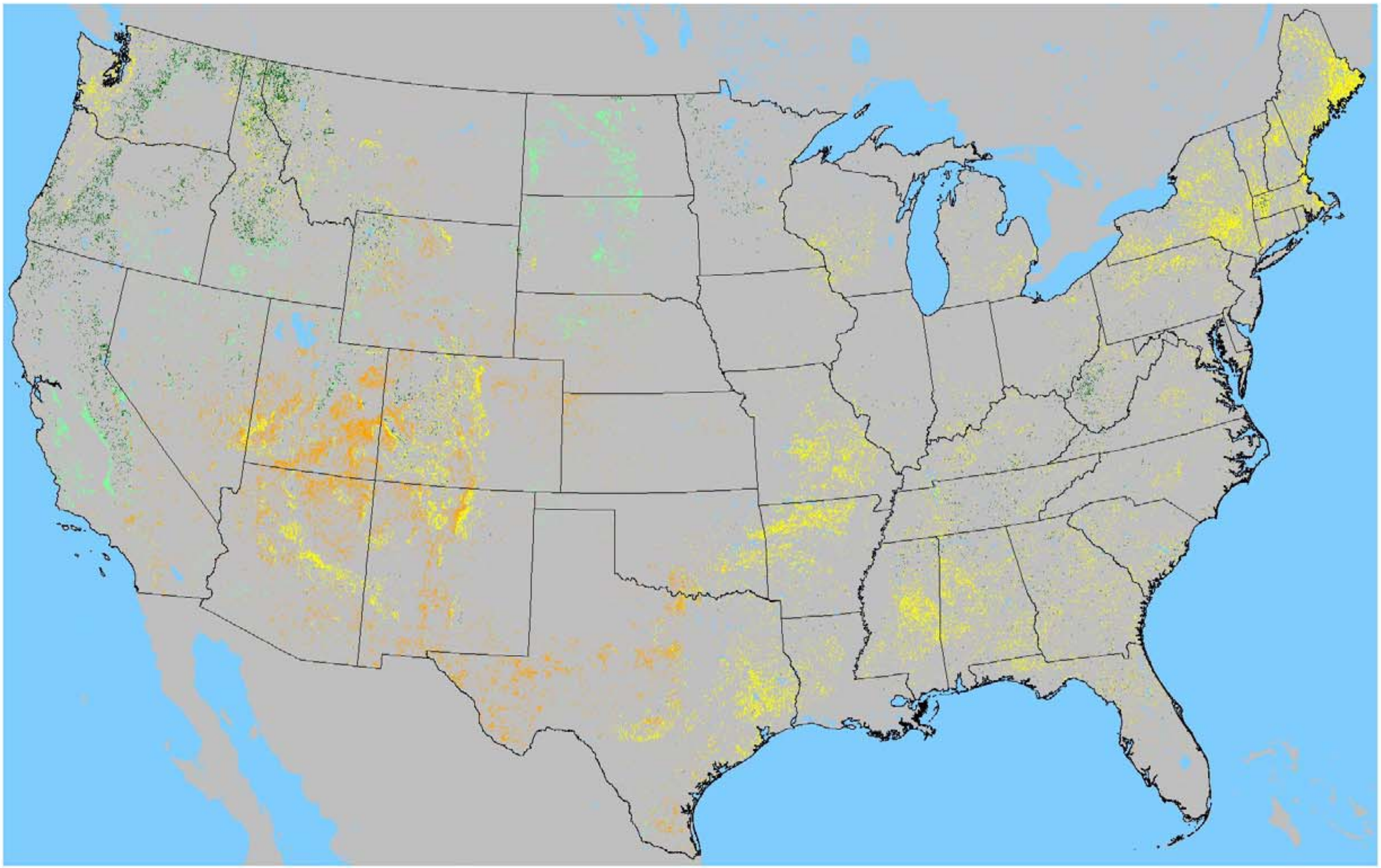
Seasonally Integrated NDVI

Regions with Significant Trends in Annual Greenness: Is the slope (b) of best-fit line significantly different from 0?





Seasonally-Integrated NDVI Trends 1989 - 2000

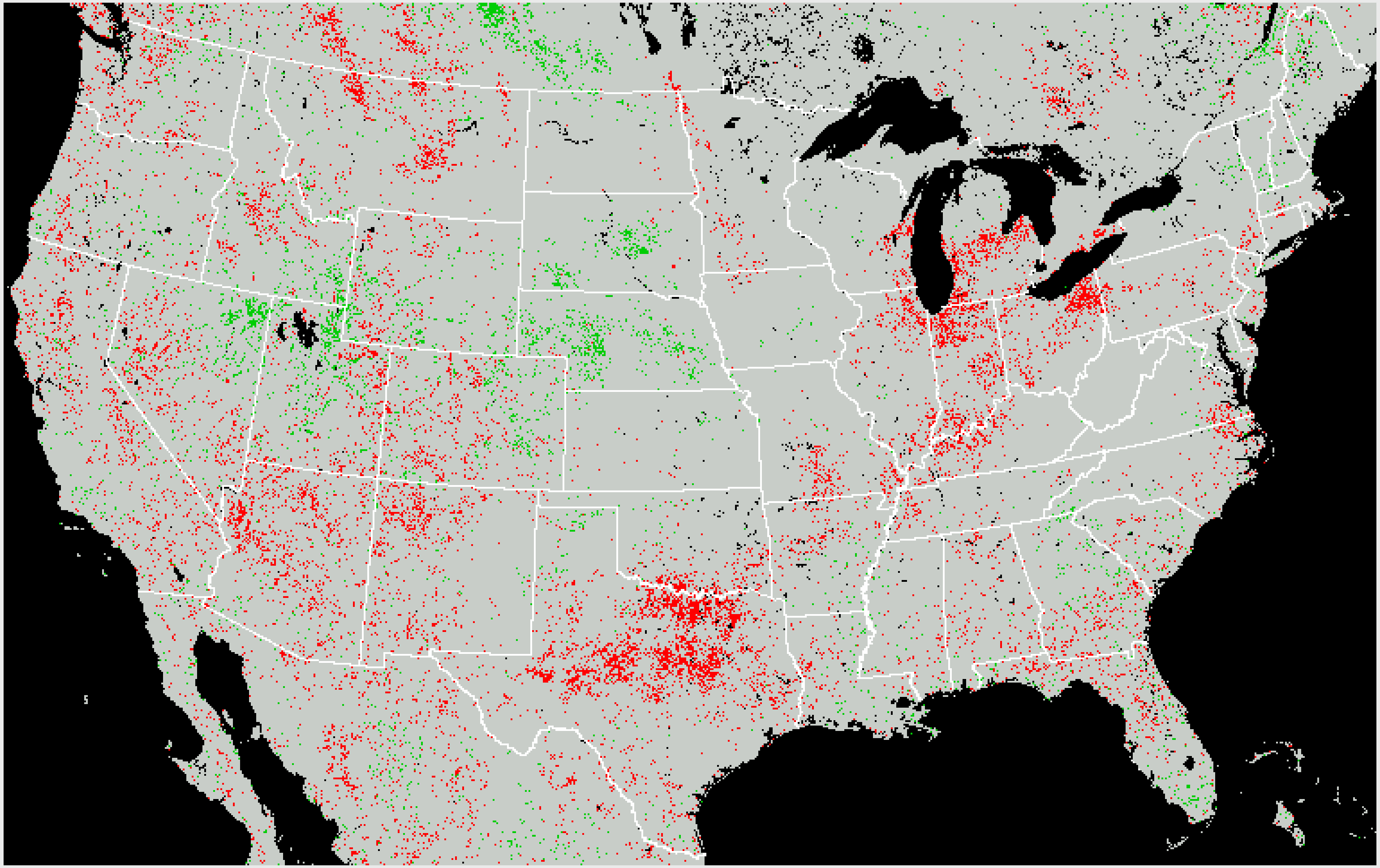


Forest/Increasing SINDVI

Forest/Decreasing SINDVI

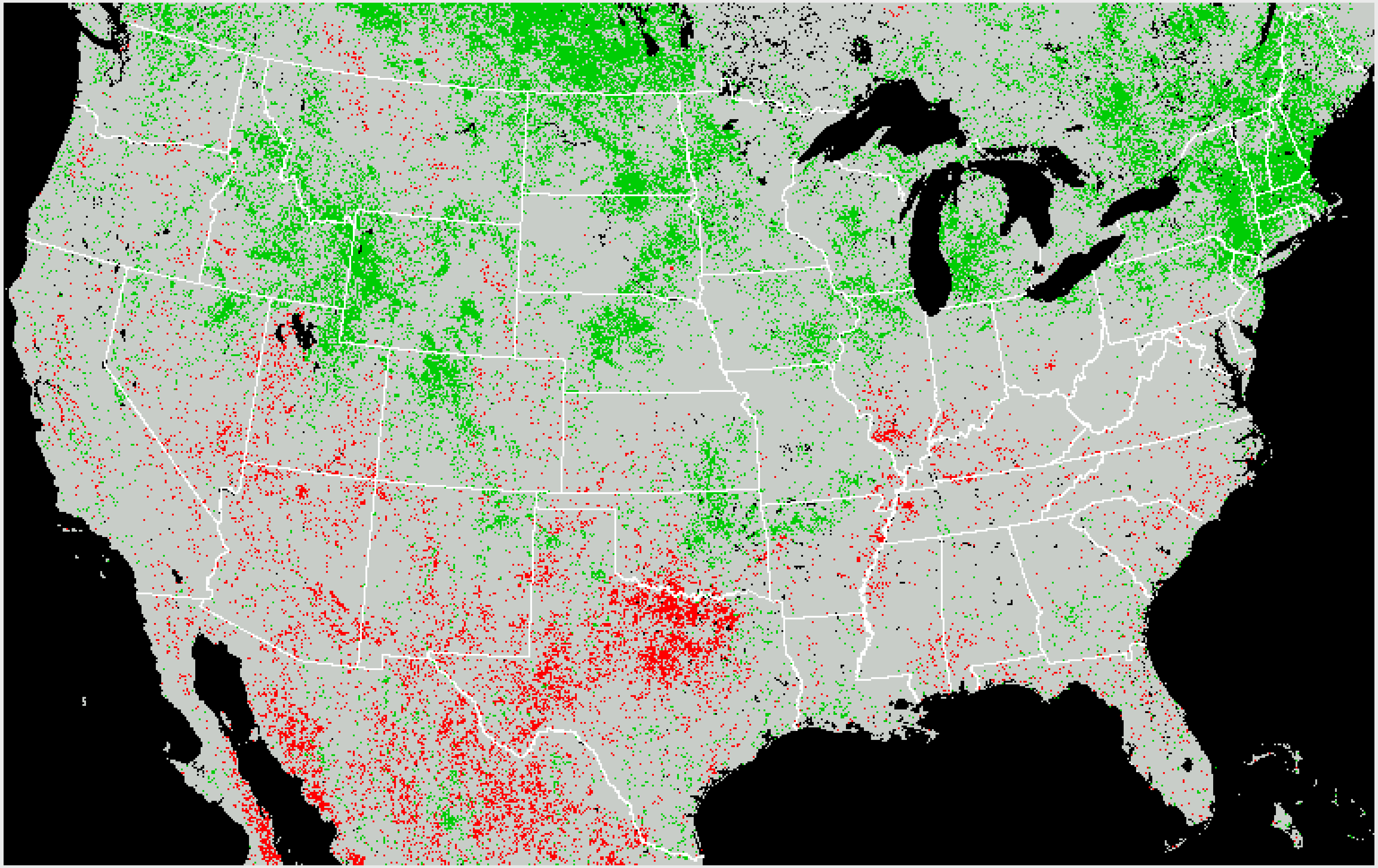
Grassland-Shrub/Increasing SINDV

Grassland-Shrub/Decreasing SINDV



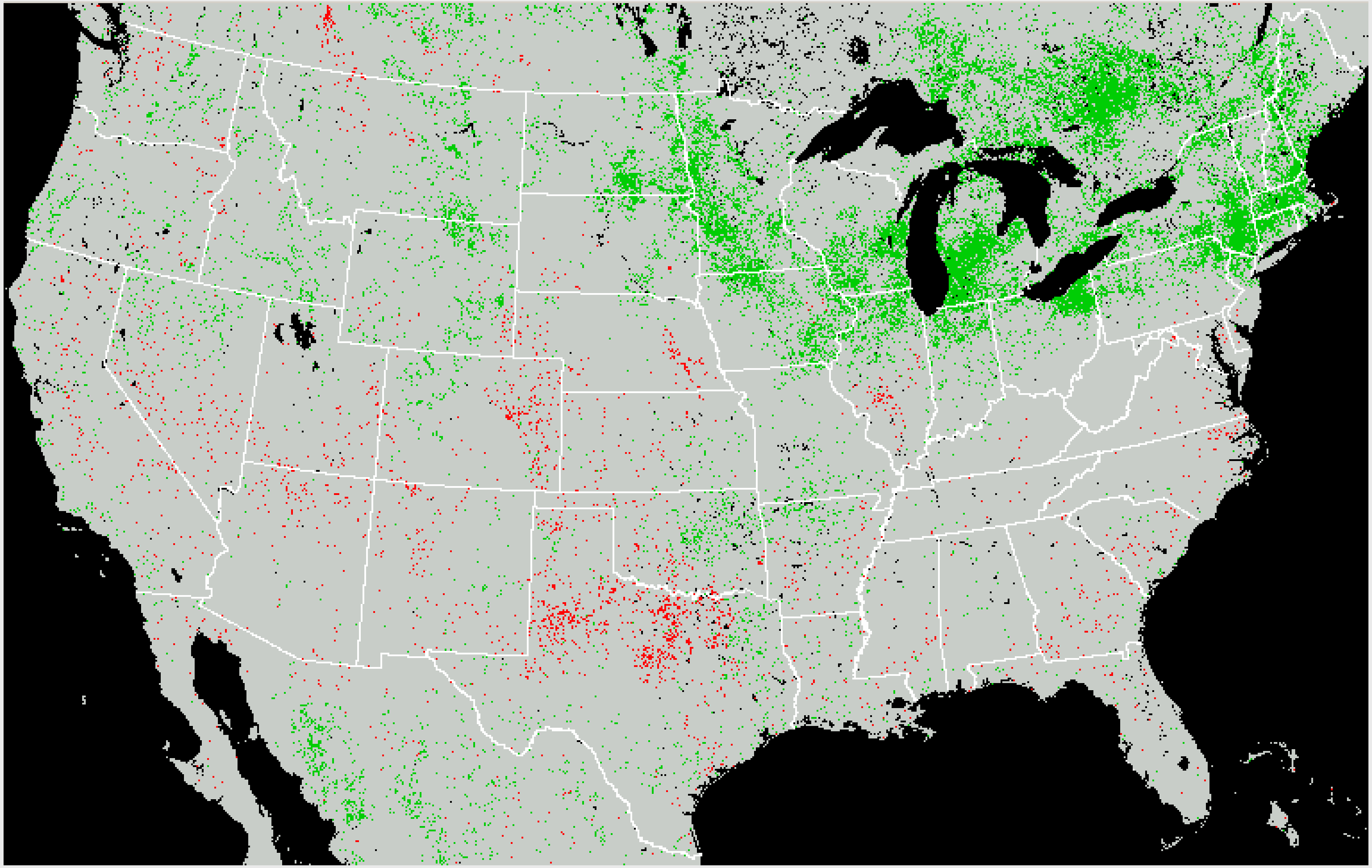
Earlier SOS
Later SOS

Trends in SOS Time 1989-2001



Earlier EOS
Later EOS

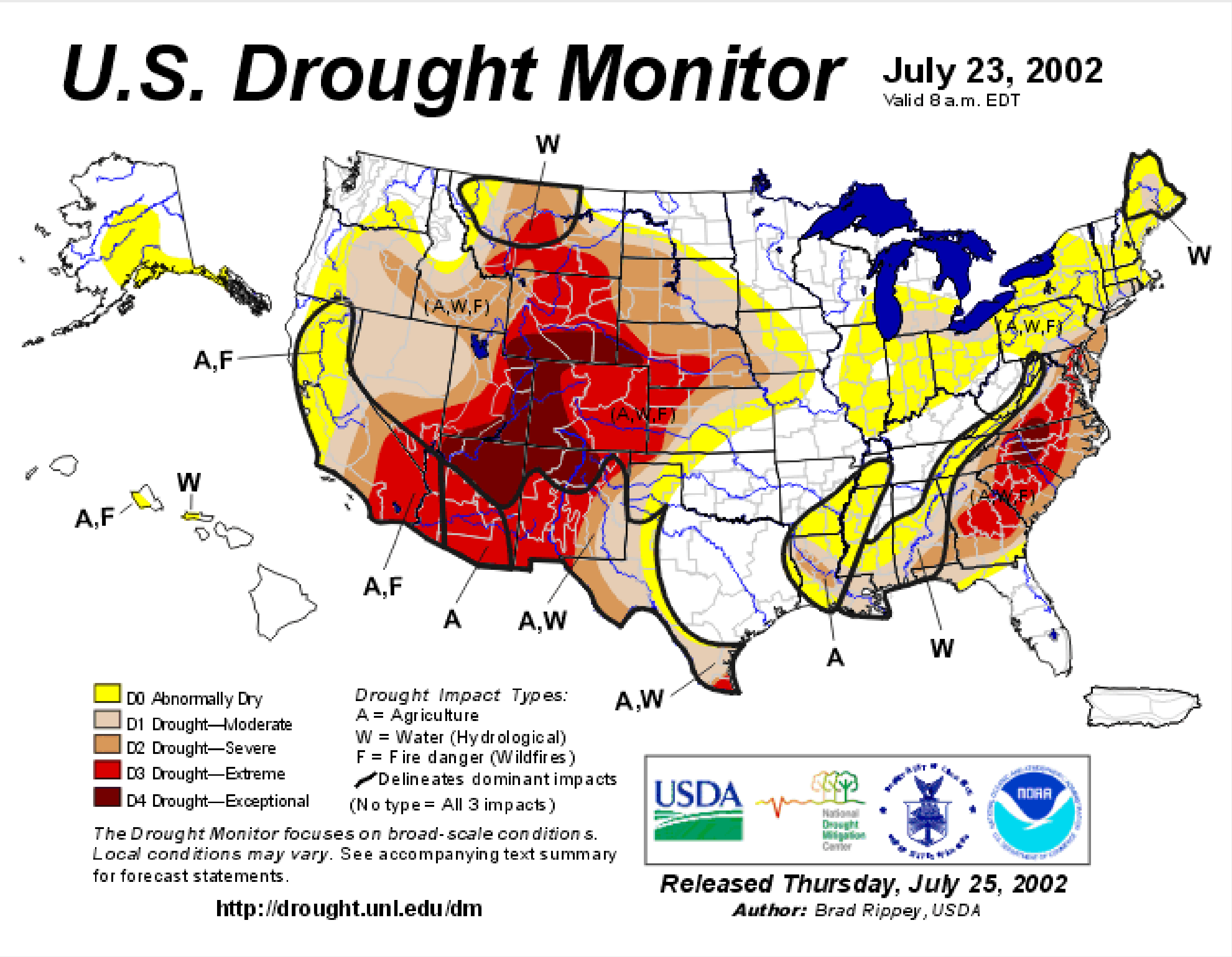
Trends in EOS Time 1989-2001



Shorter Duration
Longer Duration

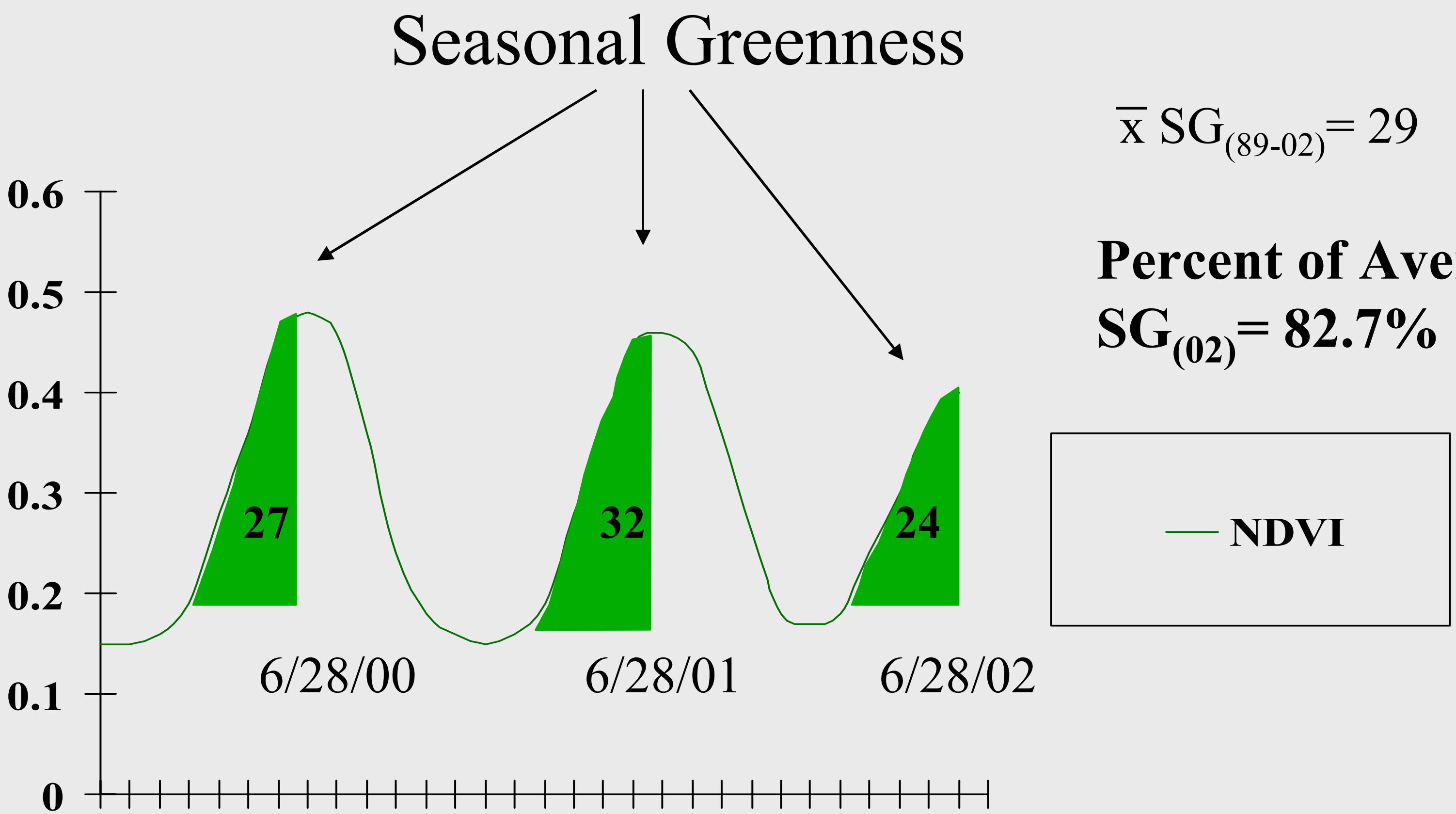
Trends in Duration of Season 1989-2001

National Drought Mitigation Center Product



- Timely summary of current drought condition for U.S.
- Provides general mapped information
- Broad-scale map lacking spatial detail, so some interpretation is necessary
- Product is not digital or geo-spatial

Satellite-based Measures of Vegetation Condition (Percent Average Seasonal Greenness)



$\overline{x}$ $SG_{(89\text{-}02)} = 29$

Percent of Average $SG_{(02)} = 82.7\%$

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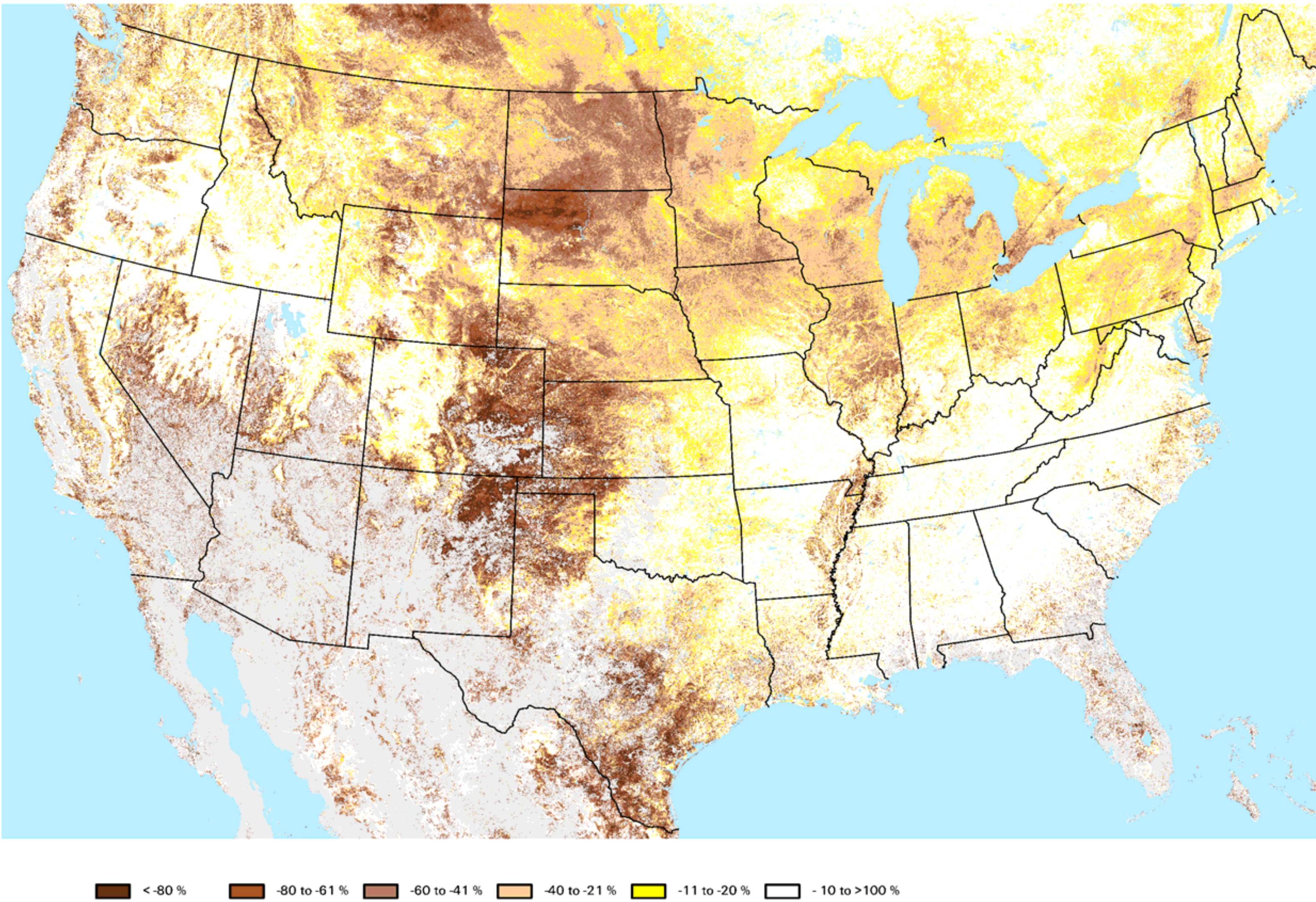
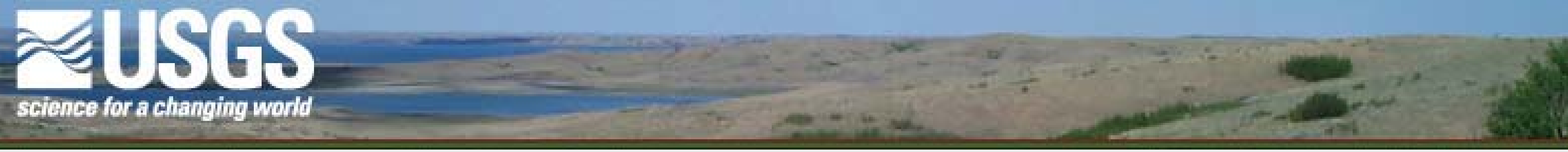
Percent of Average Seasonal Greenness
July 25, 2002

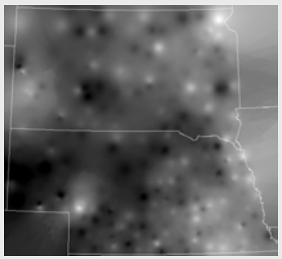




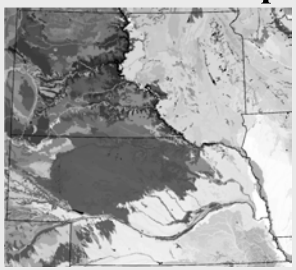
Methodological Approach

Model Input

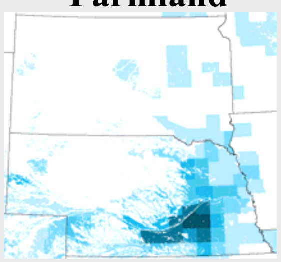
SPI 7/18/02



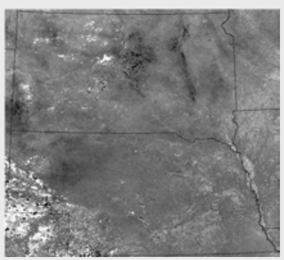
Available Water Capacity



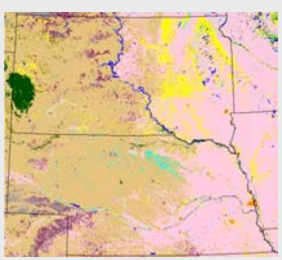
Percent Irrigated Farmland



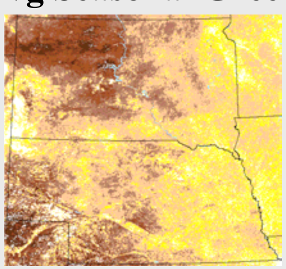
Start of Season Date



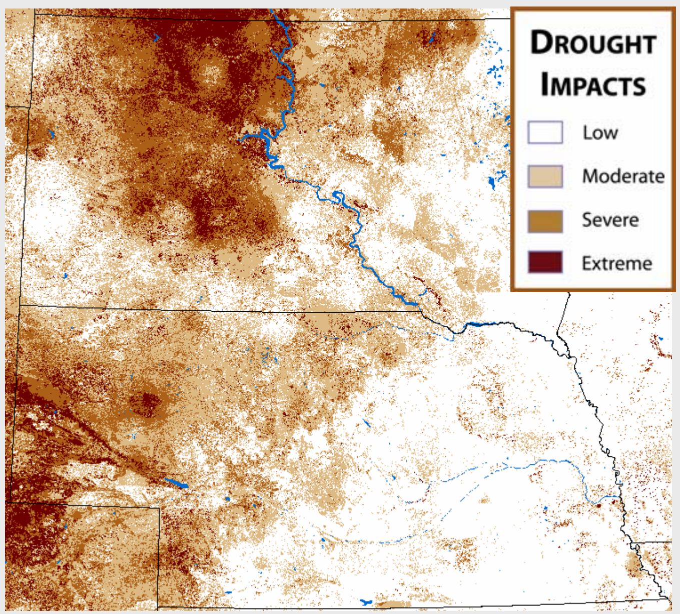
Land Cover



% Avg Seasonal Greenness



Regression Tree Modelling

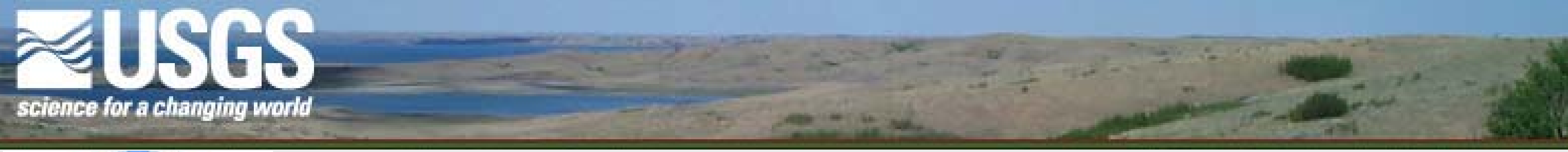


Drought Impact Index

Identify variables contributing to drought impact

"Facts as such, never settled anything. They are working tools only. It is the implications that can be drawn from facts that count, and to evaluate those requires wisdom and judgment…"

Clarence Belden Randall



USGS Geographic Analysis and Monitoring

http://mapping.usgs.gov/gam.html